DENTAL METALLURGY

W. BRUCE HEPBURN

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NOTES ON DENTAL METALLURGY

NOTES ON
DENTAL METALLURGY

FOR THE USE OF DENTAL STUDENTS AND PRACTITIONERS

BY

W. BRUCE HEPBURN, L.D.S. (Glasgow)
LECTURER ON DENTAL METALLURGY AND VISITING DENTAL SURGEON IN THE GLASGOW (INCORPORATED) DENTAL HOSPITAL AND SCHOOL

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PREFACE

THIS book of notes has been compiled for the use of dental students preparing for the British, Colonial, and American dental degrees, the various college and school requirements having been consulted, and the necessary matter supplied, so far as these requirements come within the scope of metallurgy proper. Obsolete theories regarding the composition and behaviour of amalgams have been avoided, and only the opinions of the most authoritative have been included.

In the text the attempt has been made to describe only those processes for extraction of metals which are at present employed, obsolete processes being omitted, unless where brief reference to these assists in the understanding of present-day methods. The chapters dealing with pyrometry, casting of metals, testing of amalgams for their physical properties, are inserted to meet special college requirements; while that dealing with the behaviour of metals in the mouth is intended to direct the attention to what might be termed "applied metallurgy," an aspect of the subject which the writer considers has been neglected.

The book should appeal to the general dental practitioner, presenting as it does the subject in a condensed fashion, and furnishing him in the text and Appendix with the composition of many useful and valuable alloys and solders.

No claim of originality is made for any matter contained in the text. Acknowledgment is made where a direct reference can be traced; and should such be omitted in any instance, the writer would proffer his humblest apologies.

Where different opinions are held, he has attempted to avoid theories in favour of practice, especially where the practical experience has been gained after years of observations. In this way he hopes to have presented the subject as it is, and to guard the student from imbibing theories in mistake for practice.

He has to acknowledge with thanks the valuable assistance rendered him by Dr. H. Mackay, L.R.C.P. and S. (Edin.), L.F.P.S., L.D.S. (Glasg.), Examiner on Dental Metallurgy to the Royal Faculty of Physicians and Surgeons, Glasgow. He is also greatly indebted to A. Campion, Esq., Lecturer on Metallurgy to the Glasgow and West of Scotland Technical College, for correcting the proofs; to Sydney Smith, Esq., M.A., for general corrections in the text; and to Messrs. C. Ash and Sons, the Dental Manufacturing Company, and others, for their kindly assistance in answering all questions addressed to them, and he wishes to take this opportunity of expressing his thanks to them.

WALTER BRUCE HEPBURN.

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NOTES ON DENTAL METALLURGY

CHAPTER I

PHYSICAL PROPERTIES OF METALS

METALS as a class may be said to possess certain generic properties which distinguish them from the non-metallic elements.

Thus, they may be regarded as possessing, in varying degrees, the properties of malleability, ductility, elasticity, tenacity, conductivity, weldability, toughness, density, specific heat, crystallization, odour and taste, galvanic action, hardness, occlusion of gases, lustre, fracture, sonorousness, diffusibility, volatility, and flow. At ordinary temperatures metals are solid, with the exception of mercury, which is liquid at ordinary temperatures, and solid at −39° C. They are all fusible; in mass they are opaque; they are diffusible on melting, and may be alloyed.

MALLEABILITY is the property of being permanently extended in all directions without rupture, either by pressure or hammering.

Gold is the most malleable of all the metals, and has been laminated into foil of such extreme thinness as $\frac{1}{282000}$ inch. Malleability is greatly affected by the degree of purity of the metal; the purer the metal, as a rule, the greater the malleability. (See Alloying.) It is also affected by the temperature at which the metal is worked, some metals fracturing if rolled when cold, others exhibiting the opposite tendency. Zinc, for example, fractures if rolled when cold or at a red heat, but is readily reduced in thickness if rolled at 150° C.

Annealing has a powerful effect on malleability, the latter being increased generally if annealing is resorted to. Annealing generally consists in raising the temperature of the metal, and allowing it to cool more or less slowly. Processes for annealing vary, and are mentioned where necessary in the treatment of the individual metals. Annealing may be said to cause the molecules of the metals to rearrange themselves in their original conditions, thus permitting hammering, rolling, drawing, etc., without unnecessary thinning or tearing of the metal.

Relative degrees of malleability are determined by hammering or rolling the metal when in the cold state, and registering the reduction of thickness which can be produced without annealing.

The following are in order of malleability by rolling: Gold, silver, aluminium, copper, tin, lead, platinum, zinc, iron, and nickel.

By hammering (malleability proper): Lead, tin, gold, zinc, silver, aluminium, copper, iron, platinum, and nickel.

DUCTILITY is the property of being permanently elongated by a tensile force, or of being drawn into wire, and is possessed by most malleable metals in varying degrees.

Purity of the metal influences ductility generally, although alloying in many instances increases ductility. While this is true generally, tenacity affects ductility more than malleability. Heat effects ductility, which generally decreases as the temperature is raised, but a regular ratio does not exist between ductility and temperature. Iron, for instance, is less ductile at 100° C., and more ductile at 200° C., than when at 0° C. The rate at which the tensile force is applied affects ductility, as also does the temperature and duration of annealing; gold, platinum, and silver, for example, requiring frequent annealing and drawing at very moderate speed.

The following are in order of ductility: Gold, silver, platinum, iron, nickel, copper, aluminium, zinc.

ELASTICITY is the extent to which a metal may be elongated by tension, without remaining permanently extended on the removal of the stress which caused the elongation.

The point at which the elasticity and the stress applied exactly counterbalance each other is referred to as the "limit of elasticity"—that is to say, the point which the metal has reached when a greater stress or stretch would cause the shape of the metal to be permanently altered. Such alteration, when it does occur, is referred to as the "permanent set," and the point at which it occurs is termed the "yield point."

Experiments have gone to show that fibrous metals in bar form are increased in rigidity if strained just beyond their limit of elasticity, the strain bringing the fibres of the metal closer together. The same may be said of certain non-fibrous metals, only to a less extent. The elasticity of a metal is powerfully influenced by the presence of impurities, and by methods of straining annealing, and alloying.

TENACITY is the property of resisting fracture when subjected to a tensile or stretching force.

This property in a metal is also affected by the presence of impurities, methods of annealing and alloying. Gold is readily affected by even traces of such metals as lead, bismuth, and antimony, losing its ductility and malleability, and being changed into a brittle and unworkable condition. (See Properties of Gold.)

Phosphorus has a marked effect if present in malleable iron. Karsten states that 0·3 per cent., while not sensibly affecting the tenacity, increases the hardness; while 0·5 per cent. diminishes the tenacity, and the metal shows signs of deterioration.*

As tested for relative tenacity, the metals occur in the following order: Steel, iron, copper, platinum, silver, gold, zinc, tin, and lead.

CONDUCTIVITY is the power possessed by a metal to conduct heat and electricity.

Metals as a class are regarded as the best conductors, and, as with the other properties, the conductivity may be powerfully influenced by the presence of impurities. Thus, copper for electrical purposes must be as pure as possible, as any trace of silver (the metal with which it most frequently occurs) reduces this power very considerably. Silver and copper, when pure, rank highest amongst the metals for the property of conductivity, yet if alloyed, or present in each other in even small traces, the property is much reduced. Temperature plays an important part in the conductivity of metals. If the temperature is raised, the conductivity decreases; if it is lowered, the conductivity increases. As zero is approached, the conductivity of metals becomes more uniform. The metals are arranged in their relative powers of conductivity as follows, silver in the pure state being taken as the highest, and representing 100: Silver, 100; copper, 73·6; gold, 53·2; tin, 15·2; iron, 11·9; steel, 11·6; lead, 8·5; platinum, 8·4; German silver, 6·3.

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* Greenwood.

WELDING is the property possessed by most metals of being joined by pressure or hammering without the aid of solder.

This property is possessed to a remarkable extent by platinum, gold, and iron. Platinum is welded from the finely divided deposited form into sheets, bars, etc., heat being unnecessary (see Platinum Reduction) ; so also is gold, as employed for filling purposes, in matt, cubes, foils, etc. Heat is generally essential to effect complete union or cohesion of the metals. For iron as malleable iron, or for soft steel as treated industrially, heat is employed, and clean surfaces of the metal brought together, the union being then effected either by hammering or rolling. Welding, to be complete, must disclose a perfect union of the join or section, as loose interweaving of the metallic fibres or crystals is not sufficient. A gold filling perfectly inserted should not show any tendency to disintegrate, and under the microscope should show a homogeneous structure. The term " cohesive," as especially employed in dental literature to gold, refers to this property only, which is possessed by the metal to such a remarkable degree.

TOUGHNESS is the power possessed by a metal of resisting fracture by bending or rolling. Or, " the property of resisting separation of the molecules after the limit of elasticity has been passed."*

HARDNESS is a property possessed in varying degrees by all metals, and is the resistance offered by the molecules of a substance to separation by the penetration of another body.

DENSITY, OR SPECIFIC GRAVITY.—As a rule the specific gravity of the metals is recorded when they are in the pure and cast condition, as any process which will tend to bring the molecules into more intimate contact, such as hammering or rolling, will increase the specific gravity. Zinc when freshly cast is highly crystalline, and has a specific gravity of 6·68, whereas on being rolled this is increased to 7·2. Annealing, again, will reduce the density.

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* Sir W. Roberts-Austin.

SPECIFIC HEAT.—Metals, like other bodies, have their specific heat, and to measure the relative specific heats, the amount of heat necessary to raise water from 0° C. to 1° C. is taken as the unit. Lowering the temperature of the metal generally decreases the specific heat.

CRYSTALLIZATION.—All metals are said to be capable of crystallization, by which is meant that the molecules arrange themselves in a certain geometric order in the process of the metal cooling from a gaseous or liquid state to the solid. While few metals are found native in the crystalline form, many of them may be deposited as crystals by passing a current of electricity of low intensity through a solution of the metal, or by fusion followed by slow cooling. Gold in the matt and crystalline forms are good examples of this property. (See Filling Golds.) Metals in the cast state frequently exhibit the crystalline forms, which forms are influenced by the manner of casting, the rate of cooling, and the temperature at which the metal is poured. This property is more fully dealt with under the separate metals.

ODOUR AND TASTE.—Metals are said to possess characteristic odours and tastes. Arsenic, for example, when heated, evolves a garlic odour, and to the tongue has a sweetish taste. Zinc also has a characteristic odour when burned or excessively heated, the metal, on being reduced to the oxide, burning with a bright flame, and giving off the white flocculent oxide. Alloys, as used for filling purposes, possess odours which become more pronounced when the alloys are amalgamated with mercury. The most common odour resembles a sulphide, but varies even in separate mixings of the same alloy. Essig attributes this odour to a ~~voltaic~~ action set up galvanic between the metals on the addition of the mercury, but this theory must be accepted with many reservations.

GALVANIC ACTION.—From a dental standpoint, the galvanic action between metals assumes much importance, when we consider the metals employed as filling materials. The action is generally most pronounced in mouths where the saliva is acid to litmus-paper, and where two fillings of different compositions are brought into contact, or are in fairly close proximity, the saliva in this case completing the circuit. Gold and amalgam fillings, and gold and dental alloy dentures, are common sources of this trouble, the pulps of the teeth responding to the galvanic action between the metals. In such cases, where gold and amalgam fillings are at fault, the filling should be either in gold or in amalgam, or the pulp protected by a coating of oxyphosphate of zinc cement, which acts as a non-conductor. In such mouths it is frequently observed that the fillings are corroded or washed out, especially towards the cervical margins, which may be attributed to the solvent action of the saliva and the current generated. (See chapter on Behaviour of Metals in the Mouth.)

OCCLUSION OF GASES.—All metals may be said to be capable of occluding hydrogen or oxygen gases. Palladium can occlude 500 times its volume of hydrogen, gold 50, and platinum slightly less. Silver has a greater affinity for oxygen, the occlusion causing the "spitting" of the metal during the process of solidification. (See Silver.)

LUSTRE.—Lustre has long been regarded as characteristic of metals, and is due to the high degree of opacity possessed by them, the light on this account being reflected from their surface.

FRACTURE.—The fractures of metals are described as crystalline, granular, fibrous, columnar, or conchoidal. Impurities, the method of fracture, and the rate of cooling, influence the character of the fracture. Sudden cooling generally prevents the formation of crystals, while slow cooling hastens it.

SONOROUSNESS of metals is well known, the clear note of a bell of silver, the resonance of steel wire in a piano, being common examples. The sonorousness of copper and gold is increased by alloying, " bell metal," for instance, being an alloy of copper and tin. Aluminium possesses it to a less extent, but is influenced very considerably by the method of casting.* (See Aluminium.)

Metals are capable of behaving, under suitable conditions, in the same manner as liquids ; thus, from the solid state they pass into the liquid, then into the gaseous, and by cooling can be brought back to the solid. They are diffusible, and under pressure yield before it, this property being referred to as the " flow of metals " even when the metals are in the cold or solid condition.

FLOW OF METALS.—Professor Springs has demonstrated that metals, when subjected to pressure, behave in a manner closely resembling liquids. By means of a suitable press, the metal lead was made to flow into all the crevices of the press, and was found to have penetrated the less compact structure of the metal composing the press.† (See Preparation of Alloys by Compression.)

DIFFUSIBILITY OF METALS.—This property varies greatly with the different metals. Some diffuse with great freedom, while others remain as mixtures, and constantly disclose a tendency to separate or liquate on being remelted and allowed to cool. Advantage is taken of this property in manufacturing alloys or compounds of metals, which, if not disclosing an affinity for one another, will at least remain diffused sufficiently long for the purpose intended. Copper diffuses itself through gold with great freedom, so much so that 1,000 ounces of gold and 100 ounces of copper alloyed show on analysis a variation not greater than $\frac{1}{1000}$th part between the alloy first poured and the last. (See Alloys.)

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* Faraday.

† Sir W. Roberts-Austin.

Metals differ widely in their behaviour under the influence of heat. Tin and lead fuse below the point of redness; gold, silver, and copper, at higher temperatures; while platinum, iridium, osmium, etc., are infusible in ordinary furnaces, requiring the use of the oxyhydrogen blowpipe.

VOLATILITY is the property of being converted into a state of vapour by the application of heat, and is possessed by most of the metals. Zinc, cadmium, and mercury, are very volatile, cadmium passing into the gaseous state without becoming liquid. Advantage is taken of this property in separating highly volatile metals from their ores, such as mercury, zinc, etc.

MAGNETIC PROPERTIES OF METALS.—Metals differ widely in their behaviour when placed in a magnetic field, and may be classed as paramagnetic or diamagnetic. A paramagnetic metal assumes a direction parallel to the magnetizing force. A diamagnetic metal assumes a direction at right angles to the magnetizing force.

Paramagnetic metals: Iron, nickel, cobalt, platinum, palladium, and osmium.

Diamagnetic metals: Silver, gold, copper, tin, zinc, mercury, cadmium, and lead.

Alloying affects the magnetic properties of metals; copper, for instance, a diamagnetic metal, if alloyed with even a small quantity of iron, becomes paramagnetic. Heat and the presence of impurities also affect this property. Metals differ widely as to the length of time they will retain the magnetism imparted to them ; thus, while it is more difficult to induce hard-tempered steel to accept magnetism than soft iron or soft steel, it retains the induced magnetism much longer than either of the latter.

CHAPTER II

TERMS USED IN METALLURGY

Ore.—Applied to the minerals as they occur in the crude state, from which the metals are extracted. The ore is washed at the mines to free it from as much extraneous matter as possible, and the metallurgical interest in it begins. Only such ores as contain metals in quantities or forms as to enable them to be extracted profitably are treated.

Ores may contain metals—

In the native or metallic state—*e.g.*, gold, silver, copper, mercury, and platinum.
As oxides—*e.g.*, oxides of iron and tin.
As oxides combined with water—*e.g.*, brown hæmatite or limonite.
Combined with sulphur, arsenic, antimony—*e.g.*, lead sulphide.
Combined with halogens—*e.g.*, silver chloride.
As acid salts—*e.g.*, lead sulphate.
In a state of mixture or combination of the same metal.
As a combination of various metals and various compounds of these metals.

Metals are divided roughly into two divisions—*i.e.*, noble and base metals.

NOBLE METALS are those which are readily separated from combinations with oxygen on being heated to redness.

BASE METALS are those which do not readily yield their combination with oxygen by the aid of heat only.

Gangue, Matrix, or Vein-Stuff.—Applied to the refuse or extraneous earthy matter associated with the ores.

Smelting.—Applied to the process or series of processes in which, by fusion, a metal or metallic compound is separated from its ores.

Flux.—Applied to the materials which are added to the ores to facilitate the reduction, or which may already be present in the ores, as silicates with ores of iron. Fluxes combine with extraneous matter to form fusible compounds, which, as the metal is reduced, rise to the surface and may be drawn off, removing much of the impurities present in the form of a fusible slag. In much the same manner as borax is employed in soldering, to keep the surface to be soldered free from a layer of oxides or other impurities, which would hinder union of the surfaces by the solder.

Slag.—Applied to the compound of flux and extraneous matter separated from the metallic ores during the process of smelting.

Matte.—Applied to describe arsenides, antimonides, and sulphides of metals.

Regulus.—Applied frequently to the sulphide formed when ores of iron, silver, or copper, are smelted with substances containing sulphur.

Speiss.—Applied to the arsenide of a metal.

Distillation.—Applied when a volatile metal is converted into a vapour, and subsequently collected by condensation.

Calcination.—Applied to the processes for expelling carbonic acid, water, and other volatile constituents, by heat.

Roasting.—Applied to processes for heating ores and compounds in an oxidizing atmosphere.

Desiccation.—Applied to the drying process certain ores are subjected to previous to reduction.

Dissociation.—Applied to the splitting up of chemical compounds by heat, electricity, or other measures, into the composing elements. Most strictly applied to such as are capable of being re-formed.

Cementation.—Employed to describe the diffusion of solids, such as carbon into iron (cementation process), or the recovery of silver from solid gold, the term "cementation" being derived from the cement or compound employed for this purpose.*

Liquation.—Applied to the process employed to separate two metals whose melting-points are widely different, the more fusible metal separating when its melting-point is reached. Also employed to denote the tendency, in many alloys, for the metals comprising the alloys to separate and arrange themselves according to their specific gravities.

Eliquation.—Applied to the process which consists in alloying a metal with three or four times its weight of lead (especially silver), casting it into round discs, and then applying moderate heat; the lead fuses, carrying most of the silver with it. (See Lead and Silver.)

Lixiviation.—The process of washing or leaching, employed to separate certain soluble compounds in ores from impurities or insoluble residues.

Scorification and Cupellation.—Described under Gold and Silver.

Sublimation. — Almost analogous to distillation, except that the metal is separated as a vapour and condensed to the solid.

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* Sir W. Roberts-Austin.

Dry Process.—Applied to the series of processes in which heat is employed to extract metals from their ores.

Wet Process.—Applied to the series of processes in which suitable solvents, such as ordinary acids, are employed, and the metals then deposited by means of electricity or other reagent.

There are two terms employed in metallurgy sometimes included among the physical properties of metals—*i.e.*, "cold short" and "red short."

Cold Short.—By "cold short" is meant that property in a metal which will not permit of its being rolled or hammered while in the cold state without fracture or Zinc tearing at the edges, even although it will work readily while at a red heat or even higher temperature.

Red Short.—By "red short" is meant that property in a metal which will permit of its being rolled or hammered while in the cold state, but which causes it to fracture or tear at the edges when worked at a red heat or higher temperature.

CHAPTER III

COMBINATION OF METALS AND NON-METALLIC ELEMENTS

METALS combine with certain non-metallic elements to form new classes of bodies. These are—

CHLORIDES.—All metals combine with chlorine to form metallic chlorides. The same metals may combine with chlorine in different proportions ; we may have, for example, stannous and stannic chlorides, mercurous and mercuric chlorides. These chlorides are formed—

1. By bringing a current of chlorine gas into contact with the metal when strongly heated, or when in the form of the oxide, as detailed under the chlorination process for extraction of silver.
2. By acting upon the metals with hydrochloric acid.
3. By dissolving a metallic oxide, hydroxide, or carbonate, in hydrochloric acid.
4. By substituting one metal for another, as with mercuric chloride and tin.
5. By acting upon certain metals, such as gold, with aqua regia.

BROMIDES.—Metals combine with bromine to form metallic bromides only with less readiness than with chlorine.

IODIDES.—Metals combine to form iodides, with properties closely resembling chlorides and bromides.

SULPHIDES.—Metals combine with sulphur to form sulphides. Many of the metals occur in the ores combined with sulphur as natural sulphides, such as iron pyrites, zinc-blende, and galena. Some metals exhibit a natural affinity for sulphur ; advantage is taken of this property in the reduction of metals from their ores, iron in several instances being added to the ore so that it may combine with the sulphur, for which it exhibits a strong affinity. Metallic sulphides may be artificially prepared by passing sulphuretted hydrogen through a solution of a metal, also by heating a metal in presence of sulphur, the metal being coated with a superficial layer of sulphide. This action is well marked with inferior grades of dental alloy, and in silver amalgam fillings the excess of silver induces the formation of a superficial layer of silver sulphide. Metallic sulphides are mostly insoluble in water, are solid at ordinary temperatures, and most of them fuse at a red heat.

OXIDES.—Many metals are oxidized by exposure to air ; iron, for example, soon becomes coated with rust. Others, such as lead and zinc, are converted to their oxides if heated beyond their melting-points. Oxides may be formed artificially by treating some metals with nitric acid, and from hydrated oxides by the application of heat. The metallic oxides assume their greatest importance in reduction processes, in which the object is to convert a metallic sulphide, arsenide, etc., into an oxide, from which the metal is reduced to the metallic state. They are also used for purifying the raw metal during refining. (For metallic oxides, see especially Lead and its Reduction.)

FLUORIDES.—These compounds are formed by heating certain metals or metallic oxides in hydrofluoric acid. As a class they are easily fused, and their properties closely resemble those of metallic chlorides and bromides.

FLUXES.

Those metallurgical agents known as "fluxes" are employed to assist in the separation of foreign or extraneous substances combined with an ore, by combining with them to form a slag, thus allowing the metal to melt free. For general purposes the following are the chief fluxes employed :

1. **Lime** is used largely in iron-smelting, as it acts as a powerful base for removing silica. Dolomite, the carbonate of lime and magnesia, is largely made use of, especially as a constituent of furnace linings. (See Bessemer Process for steel.)

2. **Siliceous materials,** such as siliceous slags from other furnace charges, quartz, and natural silicates, are employed where ores containing an excess of basic materials have to be reduced.

3. **Barytes** has a similar action, and is of use especially in the concentration of nickel speiss.

4. **Metallic oxides** are used as fluxes, as instance the addition of hammer scale or iron oxide in lead-smelting.

5. **Borax** is used in cleaning and soldering gold and the precious metals.

6. **Common salt** is added to the furnace charge in treating dental workroom lemel or sweep.

7. The liquid soldering fluid much used by goldsmiths and jewellers contains a saturated solution of equal parts of borax and boric acid. The liquid flows into crevices and small spaces much better than ground borax and water, and induces the solder to flow.

8. Parr's fluxed wax mixed with borax. The wax, as it is burned out, carries the borax to the crevices to be soldered. There is also a preparation of gold solder and flux combined as a powder, especially useful in soldering in bridge or continuous gum work.

There are several other agents employed, especially in the treatment of scrap gold and brittle gold, such as potassium nitrate, ammonium chloride, paraffin wax as used to prevent oxidation during soldering of aluminium, etc.

CHAPTER IV

IRON

Symbol, Fe. Atomic weight, 55·90.
Specific gravity, 7·86. Melting-point, 1,600° C.

IRON is regarded as among the most useful of the metals, because of its valuable properties and the readiness of its reduction from the ores. In the arts of construction it is of special value, being the strongest, and at the same time among the lightest and cheapest, of the metals. The three forms in which it may be prepared—cast iron, malleable iron, and steel—render it adaptable to many purposes where great pliability, rigidity, and tenacity, are desired. The metal is very widely distributed over the earth, being found in clay, rock, and sand, and in the form of various ores, and occasionally, as in meteorites, in the metallic state. It occurs native in minute traces in basalt and lavas, as spicules. The iron occurring in basalt and lavas is known as "telluric iron"; that in the meteorites as "meteoric iron," from its supposed meteoric origin.

Iron is most frequently found combined with other metallic or chemical compounds, in which condition it is found combined with sulphur, oxygen, phosphorus, and carbon.

Meteoric Iron.—Meteoric iron has been found to contain traces of cobalt, nickel, copper, manganese, sulphur, etc., the presence of the nickel to the extent of 1 to 2 per cent., and the characteristic markings of Widmanstätten, being peculiar to this iron. To produce these markings the iron may be planed and polished, and the surface etched with dilute nitric acid. They are most frequently crystalline, or appear as parallel striæ or as rhombic foliæ, with the spaces between the markings slightly raised, showing that the nitric acid has etched the surface by dissolving out some of the components of the meteoric iron in a regular manner as they occur in the ore. At Ovifak, on the island of Disko, off the coast of Greenland, fifteen masses of meteoric iron were found, the largest of which weighed 21,000 kilogrammes,* while others of considerable weight have been found in Mexico,† Africa, Hungary, etc.

OCCURRENCE.—

Ore.	Formula.	Iron per 100 Pts. of Pure Ore.
Magnetic iron ore, or magnetite	Fe_3O_4	72
Red hæmatite, or specular iron ore	Fe_2O_3	70
Brown hæmatite, or limonite	$2Fe_2O_3.3H_2O$	60
,, ,, or gothite	$Fe_2O_3.H_2O$	—
,, ,, or turgite	$2Fe_2O_3.H_2O$	—
Spathic iron ore, or siderite . .	$FeCO_3$	48
Iron pyrites, or fool's gold . .	FeS_2	46
Clay ironstone, or argillaceous iron ore	—	17 to 50
Blackband iron ore	—	21 to 43

These are the chief sources of iron for industrial purposes; the formulæ as given will denote roughly the composition of the ores.

Magnetic Iron Ore.—Is the richest and one of the most widely distributed sources of iron. This ore, one variety of which constitutes the loadstone, is so called from its power to attract steel, and is capable of rendering

* Roscoe and Schorlemmer † Huntingdon and Macmillan.

steel magnetic. It is generally found in large masses, and mostly in Northern countries, as Norway, Sweden, Russia, and North America. A variety occurs which contains considerable quantities of manganese and zinc oxides, and is known as "Franklinite."

Red Hæmatite.—Derives its name from the blood-red colour which the ore possesses. It occurs in large masses, hard and shining, in forms varying from the kidney-like ore of Cumberland to bundles of fibres. It is found in abundance in Cumberland, Lancashire, Glamorganshire, Lake Superior, Spain, and Algeria, and is more abundant than the magnetic iron ore. It consists essentially of anhydrous ferric oxide. *Red ochre* is a soft variety of red hæmatite combined with clay.

Brown Hæmatite.—Is of practically the same composition as the red hæmatite, only containing from 10 to 15 per cent. water of hydration. It occurs as globular masses, as grains, as stalactites, as beds and veins. *Yellow ochre* is a variety of brown hæmatite. This ore is found in Cumberland, France, Spain, Northamptonshire, Lincolnshire, and Gloucestershire.

Spathic Iron Ore.—Consists chiefly of carbonate of iron, mixed with various foreign matters. Occurs combined with manganese, which renders it of special value for the production of certain steel-making alloys. It is found in Saxony, Durham, Styria, and Carinthia.

Iron Pyrites.—Contains iron and sulphur, and is largely used as a source of sulphur in the manufacture of sulphuric acid, the sulphur having been removed, and any traces of copper extracted. The remaining ferric oxide is reduced to the metallic state.

Clay ironstone and blackband are found mainly associated with coal, limestone, shale, and clay, and occur in Britain, Belgium, and Silesia.

REDUCTION.—Iron is used in three principal forms, the properties of which vary according to the percentages of carbon contained. Thus, we have cast iron, containing

1·5 to 4·5 per cent.; malleable and wrought iron, 0·15 to 0·3 per cent.; and steel, from 0·1 to over 2 per cent. of carbon. From these three varieties we have all the various preparations of the metal.

CAST IRON is the metallic product of the blast-furnace, and is the variety from which malleable iron and steel are generally prepared. It is obtained from the ore by smelting, with the addition of suitable fluxes. The types of furnaces vary, but the most commonly used type for the reduction is the blast-furnace.

The production of pig or cast iron from the ores of iron comprises two principal stages—*i.e.*, the preparation of the ores and the smelting.

The ore is prepared by submitting it to a roasting or calcination which expels water, carbon dioxide, sulphur, and other volatile substances. The process also leaves the ore in a more porous condition, and in a state more easily permeated and acted upon by the reducing gases of the blast-furnace. The calcination also converts any ferrous oxide present into ferric oxide, which does not readily combine with silica or form fusible compounds in the furnace. The ore is smelted by mixing with a quantity of fuel to act as a reducing agent, and to develop the necessary temperature within the furnace. It is also necessary to add a flux, in order to combine with the impurities of the ore to form a fluid slag. The fuel mostly used is hard coke, although in districts where the coal is non-coking it is used in the raw condition. The flux used is practically always limestone, although sometimes quicklime is used, and very occasionally an aluminous material is added. The proportions of fuel and flux added to the charge depends upon the richness and purity of the ore being smelted. The mixture of fuel and ore is charged through an opening in the top of the furnace. The fuel is kindled, and air under pressure is forced into the furnace through nozzles or blowpipes called the "twyers," which are placed round the furnace near the hearth. The twyers vary in number, from six in small furnaces to twelve or fourteen in very large furnaces. The air for the combustion is always heated by passing it through stoves, which are heated by the waste gases of the furnace. In this way a large quantity of heat which would otherwise be wasted is utilized, and a very considerable economy of fuel effected. The oxygen of the air, entering the furnace, acts on the carbon of the fuel, and is immediately converted into carbon monoxide; any small quantities of carbon dioxide formed are immediately converted to carbon monoxide by combining with an additional quantity of carbon. This carbon monoxide now acts upon the ferric oxide of the ore, with the production of carbon dioxide and metallic iron. As the fuel burns away in the lower portions of the furnace, developing a very high temperature, the whole charge gradually sinks in the furnace, the reduced iron melts and runs down into the bottom portion or crucible, the flux combines with the siliceous matter and gangue of the ore, forming a slag which melts and also runs down to the hearth, and remains in a fluid condition on top of the molten iron, as it is of a lower specific gravity. When sufficient has accumulated, the iron and slag are run off or "tapped" through holes provided for the purpose. The iron is run into sand moulds, and when cold presents the familiar appearance of pigs. The iron contains about 3·5 to 4·5 per cent. carbon, which has dissolved through contact with the fuel, also varying quantities of silicon, sulphur, phosphorus, and manganese.

The pig iron produced may be of two varieties, known as *white iron* and *grey iron*.

White iron contains nearly the whole of the carbon in chemical combination with the iron. It is usually produced in furnaces charged with the minimum quantity of fuel. Sudden cooling of the molten metal will also cause the carbon to be in combination, and thus produce white iron. White iron is very hard and brittle.

Grey iron contains the greater portion of the carbon in the uncombined or free state as graphite. It is produced in furnaces charged with a large proportion of fuel. Slow cooling of the metal produces grey iron, which is soft. The carbon separates from its chemical combination, and frequently a certain amount of graphite can be removed from the surface of the metal. Grey iron contains a considerable amount of silicon, which induces the crystallization of the carbon as graphite. White iron is principally used for the production of malleable iron. Grey iron is used for foundry purposes and for steel-making. The grades of grey iron rich in graphite are mixed with poorer grades when used for castings. Grey iron is a little less fusible than white iron. Cast iron contains from about 1·5 to 4·5 per cent. carbon. By using ores containing a large quantity of manganese in the blast-furnace, various grades of manganiferous pigs can be produced. The manganese enables the iron to hold more carbon than normal pig, the alloy having a crystalline structure with a lustrous fracture, and known as "spiegeleisen," which contains from 5 to 20 per cent. manganese and 4 to 6 per cent. carbon.

The fact that grey iron is converted into white iron by rapid cooling is made use of in the production of chilled castings. The molten grey iron is poured into massive iron moulds at those portions of the castings that are to be chilled. The surface immediately in contact with the iron mould is converted into hard white iron to a depth of, say, $\frac{1}{8}$ inch.

MALLEABLE CAST IRON is produced from white pig iron, and is largely used for small articles, such as spanners, keys, bolts, and parts of machinery, where a strong ductile material is required, but where the cost of forging would be prohibitive. The articles are cast from white iron into moulds prepared in sand in the usual way, and afterwards submitted to an annealing process. The articles are packed into iron boxes or pots with finely powdered hæmatite ore. The boxes are then placed into an annealing furnace, and gradually heated to a temperature of about 1,000° C., and maintained at that temperature for from three to ten days, depending upon the size of the castings. During this heating a large proportion of the carbon is removed from the iron by oxidation ; the remaining carbon is converted into a special form of graphite or free carbon, which is disseminated throughout the mass. Malleable cast iron is softer, tougher, and more ductile, than ordinary grey castings. The tensile strength is also very greatly increased.

MALLEABLE OR WROUGHT IRON may be produced from cast iron, either by what is known as " dry puddling " or by " pig boiling." In the former process the charge is never perfectly fluid, only reaching a pasty consistency, whilst in the latter the charge is completely liquid during the refining.

In the original process as invented by Cort, while iron was always used, and the bottom of the furnace was lined with sand, the iron remained in a pasty condition ; a certain amount of the iron was converted to oxide of iron by the action of air, and the whole mass had to be vigorously stirred to mix the oxide of iron formed with the pasty metal. The impurities were thus removed by oxidation, partly by the oxides formed during the melting, and partly by the oxide of iron added in the solid condition.

In working this process, grey iron could not be used unless it was first converted to white iron.

The modern or wet method (pig boiling) for the manufacture of malleable iron differs from the dry puddling process, inasmuch as the bottom of the furnace is lined with an oxidizing material, such as hæmatite, hammer scale, or cinder produced in the later stages of the process. Grey iron is used without previous conversion to white iron. The charge of iron is placed into the hot furnace, upon the bottom of which has been previously spread the oxidizing material. The metal is melted, and allowed to become perfectly fluid before incorporating the oxide of iron. During this incorporation of oxides, the temperature of the furnace is somewhat reduced; slags containing oxides of iron are added in order to combine to form a flux with the silica formed by oxidation of the silicon contained in the pig iron. The carbon is also attacked by the oxides, and carbon monoxide is formed, and escapes through the slag, burning with a blue flame. The escape of CO also causes an ebullition in the mass. At this stage the temperature of the furnace is again raised, to compensate for the increased viscosity of the metal which occurs as the impurities are removed. The charge is well rubbed until the ebullition ceases *and the metal comes to nature.* The metal is then agglomerated into lumps or balls, which are brought to welding heat, removed from the furnace, and hammered into blooms. The hammering expels the slag from the metal, which is then rolled into bars or other sections desired.

STEEL may be produced by— an alloy [illegible]

1. The cementation process.
2. The crucible or pot process.
3. The Bessemer or pneumatic process.
4. The open hearth processes.

It is by these four methods that practically all the steel which is used at the present time is produced.

Cementation Process.—This is the process in general use for the manufacture of a large proportion of tools and cutlery steel. Best Swedish iron, known as "Walloon bar," is used in the form of flat bars. These are packed in charcoal in fireclay pots or boxes, which are hermetically sealed so as to exclude the air. These boxes form an integral part of the cementation furnace, and are set over a long grate. The temperature of the furnace is gradually raised to a bright red heat, and maintained at it for a period of seven to fourteen days, according to the content of carbon required in the finished steel. The carbon is gradually absorbed, and penetrates the mass of iron, converting it into steel. The furnace is allowed to cool for a number of days, and the bars withdrawn. The bars when removed from the pots are covered with blisters—hence the name "blister steel." The bars are made into bundles or "faggots," heated to welding temperature, and hammered. This product is known as "shear steel"; if the bars are cut up and again welded, the product is "double shear steel."

Crucible or Cast Steel.—Blister steel is not sufficiently regular in composition and texture for the very finest quality of tools and cutlery; the carbon gradually decreases from the outside to the centre. This is the case even after several pilings and weldings. The better way of obtaining a homogeneous and uniform product is to cut the blister bars into small pieces, and to melt in crucibles. The metal after complete melting is kept at the highest temperature of the furnace for about fifteen minutes, to what is known as "kill" the metal. This causes an evolution of the dissolved gases and oxides from the metal, and so allows it to be cast into sound ingots.

The crucibles employed are made of a refractory clay, and are heated either in a coke-hole or gas-fired furnace. The metal is then cast into ingots, and is known as "crucible cast steel," which is afterwards reheated, hammered, and rolled to a desired size and section.

The Bessemer Process consists in blowing air through molten pig iron, by which means the various impurities are successively oxidized and removed, the result being practically pure iron, which is then recarbonized by the addition of material rich in carbon, such as pig iron or spiegeleisen, according to the temper of the steel required. The operation is carried out in a pear-shaped vessel known as a "converter." This consists of a shell of steel plates lined with a refractory material, and supported on trunnions, on which it can be rotated for the purpose of filling or emptying. A blast of air is supplied from a blower, through pipes which pass through the trunnions to the wind-box at the bottom of the vessel, and thence by twyers to the metal. The usual size of converter holds a charge of 10 to 15 tons of metal.

In the original Bessemer process, the converter was lined with ganister, a very siliceous, refactory material. This is still the case in what is known as the "acid process." Iron containing phosphorus in considerable quantities cannot be employed in the acid process, as phosphorus can only be eliminated in the presence of a strong base capable of combining with the phosphoric acid produced by its oxidation to form a stable phosphate. Hæmatite pig iron has therefore to be employed in an acid-lined converter.

The process is carried out as follows : The converter is first heated strongly by a coal or coke fire, the ashes cleaned out, and the vessel turned down to a horizontal position. The necessary amount of pig iron is poured in, the blast put on, and the vessel raised to a vertical position. The silicon and manganese are at once attacked by the oxygen of the air, forming silica and manganous oxide, with evolution of heat. The oxide of manganese, together with some oxide of iron produced, combines with the silica, forming a slag consisting of manganous and ferrous silicate. As the silicon and manganese are removed, the carbon of the metal becomes attacked, being first converted to combined carbon and then burnt ; the charge of metal boils from the escape of carbon monoxide, which burns at the nose of the vessel with a long flame, and at the same time sparks of burning iron particles are emitted. As soon as all the carbon is removed the flame disappears, and the vessel is turned down, necessary additions of spiegeleisen made, and the metal poured into ladles, and then turned into the moulds. In the basic Bessemer process the converter is lined with a basic material, such as dolomite or magnesite. The procedure is the same as in the acid process, up to the point where the carbon is removed—drop of the flame. At this stage, instead of immediately turning down the vessel, the blowing is continued for several minutes longer, and additions of lime are made. It is during this period, known as the " after-blow," that the phosphorus is removed, as phosphoric acid, which combines with the lime to form a stable phosphate of lime. When the phosphorus is all removed, the vessel is turned down, the slag poured off, and the necessary additions made, and the metal is then cast into ingots.

The Open Hearth Process.—Steel can be produced by refining pig iron on the open hearth as well as in the converter. The process is usually carried out in gas-fired regenerative reverberatory furnaces. There are two principal forms of the open hearth process, known respectively as the "Siemens" and the "Siemens-Martin" process. In the former pig iron and iron ore are used, whilst in the latter a mixture of pig iron and steel or wrought iron scrap is employed. In general practice at the present time a combination of these two is usually adopted. In the Siemens process the purification of the pig iron is effected by oxidation by means of the iron ore and the furnace gases.

In the Siemens-Martin, the removal of impurities is effected by dilution with the scrap, and selective oxidation by the furnace gases.

The process may be worked either acid or basic, as in the case of the Bessemer, the acid furnace being lined with silica, and the basic with dolomite or magnesite. The capacity of the open hearth furnaces varies from 5 to 200 tons. The furnace is heated to a high temperature, and pig iron and scrap charged in; the iron melted and iron ore thrown into the bath from time to time, until all the carbon, silicon, and manganese, are removed to the desired extent.

When working a basic furnace, a pig iron high in phosphorus may be used, and lime is added to the bath to combine with the oxidized phosphorus. As in the Bessemer process, the complete removal of the carbon takes place before the phosphorus is oxidized. Small samples are drawn from the bath from time to time as the process proceeds, and are examined by appearance of fracture to determine the amount of carbon in the metal. These samples are also occasionally analyzed for carbon. When removal is sufficiently complete, additions of spiegel or ferromanganese are made, and the metal tapped into the ladle, and then cast into ingots moulds. The open hearth process is possibly the one now most largely used, and also produces the best quality of steel in large quantities. The bath of metal is completely under the control of the melter, so that steel of uniform quality can be regularly obtained.

PROPERTIES OF IRON.—Pure iron is only prepared as a chemical curiosity, and is a white, lustrous metal capable of taking a high polish. It possesses a higher fusing-point than malleable iron, and is hard, ductile, and tenacious.

Cast iron is the most impure form of iron, generally containing traces of sulphur, phosphorus, manganese, silicon, etc. It possesses the lowest melting-point, 1,200° C.; is lowest in tenacity, ductility, and elasticity. It can be readily hammered, rolled, and forged, if raised almost to fusing-point, when it becomes very plastic. Cast iron cannot be tempered, and so is useless for edge tools. Malleable iron is the purest form of iron used industrially, having the lowest percentage of carbon. It is fibrous in structure, and, as its name denotes, is malleable, ductile, and elastic. It is also known as "bar" or "wrought" iron. Malleable iron cannot be tempered. Two pieces of this iron, if heated, may be forged or welded together, a property of great value and importance.

Steel is the most important alloy of iron from a dental standpoint, and contains 0·1 to over 2 per cent. of carbon. It ranks as one of the strongest and most elastic of the metal group, these properties and its comparative lightness being important where weight is of consequence, as in the making of forceps, elevators, pliers, etc. It can also be brought to a fine edge, having the edge improved in hardness and durability by tempering. In wire (piano wire) form, steel is made use of in correcting cases of malocclusion, etc., its great strength and elasticity being most valuable. In sheet form it is used in the making of clamps, matrices, etc. Steel oxidizes or rusts rapidly when in contact with moisture, and is best protected by a plating of nickel, silver, or gold. Steel wire will not adhere to vulcanite unless it has been coated with a thin layer of tin. This is effected if the steel is moistened and coated with blue stone (copper sulphate), the deposit of copper causing the tin to adhere more readily. The hardness of steel is much affected by the percentage of carbon present; the larger the quantity of carbon, up to a certain limit, the harder and more brittle the steel. Industrially, steel is assuming more importance when alloyed with other metals, whereby its physical properties are greatly modified.

EFFECTS OF IMPURITIES IN IRON.—Silicon hardens iron, but if present in large quantities renders it brittle. Sulphur if present in large amounts causes red-shortness.

Arsenic causes cold-shortness only less markedly than phosphorus.

Phosphorus in the same quantities produces cold-shortness. The addition of ferromanganese reduces to some extent the effects of sulphur, and also acts as a deoxidizer.

ALLOYS OF IRON.

Tungsten Steel.—Tungsten added to steel greatly increases the hardness; indeed, steel cannot be hardened further unless by being heated to redness and plunged into oil, and even then the higher alloys almost invariably crack when wrought upon. Tungsten steel is largely used for machine tools, as a much greater cutting speed can be used without drawing the temper than is possible with carbon steel. These alloys generally contain from 2 to 7 per cent. of tungsten; they are sometimes referred to as "self-hardening" steels, and also as "Mushet" steels.

Tungsten added to steel from 2 to 3 per cent. increases its power to retain magnetism.*

Chrome Steel.—This alloy generally contains from 0·25 to 2 per cent. of chromium. Chromium added to steel increases the hardness, elasticity, strength, and extensibility. An excess makes the alloy very brittle. It is used chiefly as a sheathing for projectiles. Chroming increases the hardening capacity of the steel by sudden cooling.

Aluminium Steel.—This alloy must not contain more than 1 per cent. of aluminium. Aluminium added to higher-grade steel in small quantities causes it to cast better, overcomes red-shortness, increases elasticity and tenacity, and reduces oxidation; it has no effect on the melting-point, and if added to excess makes steel brittle and increases crystalline structure.

Nickel Steel.—This alloy contains from 2 to 4 per cent. nickel, and from 0·2 to 0·3 per cent. carbon. It has a higher elastic limit, and corrodes less in sea-water than ordinary steel. When "Harveyized," it is much used for armour-plating, gun-barrels, and projectiles. French smelters add from 1 to 2 per cent. of nickel to form this alloy.

Copper Steel.—In this alloy there may be as much as 20 per cent. of copper. Copper increases tenacity, strength, and malleability, which are further increased if the alloy is tempered.

Manganese Steel.—The addition of not less than 6 per cent. and not more than 14 per cent. of manganese increases the toughness and tenacity of steel, and reduces its strength and ductility; more than 14 per cent. produces a diminution in ductility.

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* Huntingdon and Macmillan

Silicon Steel.—This alloy has properties similar to those of aluminium steel, and the silicon and aluminium are in almost similar quantities in the respective alloys. The silicon slightly increases tenacity.

TEMPERING OF STEEL.—Steel is generally forged or shaped while in the soft state, the tempering or hardening being done, especially in the case of dental and surgical instruments, when the metal is ready for plating. The method employed varies with the instrument to be tempered. The process generally consists in raising the steel to the desired heat, then plunging it into water, salt and water, oil, or mercury. Finely tempered instruments, such as clamps, burs, fine enamel chisels, etc., should not be exposed to the naked flame, but coated with fat or soap, enclosed in a case surrounded by carbon, or heated on a sheet of iron embedded in sand. For new instruments, such as scalers, excavators, etc., the best results are obtained by heating the entire instrument to a dull red heat, and plunging into water, then tempering according to the colour which moves in front of the flame or heat. The following table gives the temperatures corresponding approximately to the various tints to produce the best cutting edges.

Temp. °C.	Colour.	Temper.
✓ 221	Very faint yellow	Lancets, enamel chisels, etc. ✓
✓ 232	Pale straw	Razors and fine surgical instruments. ✓
✓ 243	Full yellow	Excavators, penknives. ✓
✓ 254	Brown	Pluggers, gum scissors. ✓
266	Brown with purple spots	Pocket-knives, axes, etc.
277	Purple	Table-knives, metal shears.
288	Bright blue	Watch-springs, swords.
294	Full blue	Augers, fine saws.
316	Dark blue	Pit and hand saws.

CASE-HARDENING OF STEEL.—Articles to be hardened are packed in air-tight cases surrounded by such animal carbon producers as leather, bone dust, hoofs or horns, etc., with a little soda or lime. The box and contents are gradually heated to redness, and maintained at this heat for a time depending on depth of case-hardening required.

Superficial hardening is obtained by dipping red-hot iron into prussiate of potash, and then plunging into cold water. Case-hardening is employed where friction is to be resisted, for lathe-heads, engine bearings, etc., and imparts to the metal an extremely hard skin, which resists metal files. The process is also employed for hardening armour-plates.

HARVEYIZING OF STEEL.—This is a modification of the cementation process, whereby the outer thickness of a mild steel plate is caused to take up an additional percentage of carbon, and so acquires increased power to resist penetration. The steel to be Harveyized is laid in chests on a furnace bed of fire-bricks and sand; carbon is tightly packed around it, and the chests are covered with fire-bricks. The temperature is raised to about 1,200° C., and retained at this heat until the steel has absorbed 1 per cent. of carbon; and the carbon having penetrated as far as is required, the furnace is allowed to cool slowly. The steel produced is extremely hard on the surface, while it still possesses the properties of mild steel throughout the rest of its depth.

CHAPTER V

NICKEL

Symbol, Ni.	Atomic weight, 58·70.
Specific gravity, 8·90.	Melting-point, 1,420° C.

OCCURRENCE.—Nickel occurs chiefly combined with arsenic, and was first mentioned by Hiarni in 1694, under the name of "kupfernickel," signifying "false copper," from the fact that it resembled copper ore, and still did not yield copper. Cobalt is almost invariably combined with the metal in the ore.

The chief ores are—

Garnierite, $NiMg(SiO_3)_2 3HO$. A hydrated silicate of the metal containing from·7 to 10 per cent. nickel. It is usually associated with oxides of iron and siliceous gangue.
Nickel-blende, NiS.
Antimonial nickel, $NiSb$.
White nickel, $NiAs_2$.
Millerite, or nickel pyrites, NiS. A yellow-coloured sulphide.
Nickeliferous pyrites, or pyrrholite, the magnetic pyrites.
Kupfernickel, or niccolite, Ni_2As_2, an arsenide of nickel.

PREPARATION OF NICKEL.—The processes for the reduction of nickel ores depend on what metals occur combined with nickel. They may be divided into two classes—the dry and wet processes.

Dry Processes. — The dry processes for the reduction of nickel are extremely varied, the variations depending to a great extent upon what impurities, or what other metals, are combined with the ore. The presence of cobalt causes the processes generally to be much lengthened. The one given may be regarded as showing the essential operations. When an ore of nickel containing sulphur is being reduced, 7 per cent. sulphur is left in the ore after the first roasting. The ore is then mixed with coke or charcoal and calcium sulphide, and heated in a blast-furnace, when the slag combines with the silica and other materials in the ore, and is run off. The matt so formed is treated in a modification of the Bessemer converter, when most of the sulphur and all the iron present are eliminated in the slag. The matt is ground to powder, mixed with sulphate of soda and coal, and remelted. Any copper present separates on cooling; the two metals and the two matts are then remelted separately until the copper is free of nickel, and the nickel free of copper. The remaining sulphur is driven off, leaving the nickel present as the oxide, which is mixed with flour and oil into a paste, heated to a white heat with charcoal, when metallic nickel results, but is unfused. This "grain" or "cube" nickel is placed in iron pots, and heated in a reverberatory furnace until the nickel is compact and coherent.

The Mond Carbonyl Process. — This process consists in passing pure carbon monoxide over gently heated metallic nickel at 60° C.,* when a curious volatile compound known as "nickel carbonyl," $Ni(CO)_4$, is formed. This liquid boils at 43° C., forming a vapour which, if heated to 180° C., splits up into carbon monoxide and nickel. The CO_4 having no action upon copper or cobalt, and but little action upon iron, the nickel is thus obtained almost pure.

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* Schnabel and Louis, vol. ii., p. 636.

Wet Processes.—1. The ores are washed, picked, and roasted to drive off volatile compounds, such as arsenic, sulphur, etc. They are then digested with boiling hydrochloric acid ; bleaching powder is added to peroxidize any iron present, which is precipitated as the oxide and basic arsenide of iron. Sulphuretted hydrogen is passed through the solution, and deposits any copper present as the sulphide. The solution is next boiled to drive off any sulphuretted hydrogen, and neutralized with lime. Any cobalt present is deposited by adding a little bleaching powder, and the solution filtered. Milk of lime is now added, and the nickel deposited as the hydrated oxide.

2. Nickel may be obtained as a black powder by reducing nickelous oxide in a stream of hydrogen, or by reducing nickelous oxalate out of contact with air.

3. The metal can also be obtained by the electrolysis of an ammoniacal solution of the double sulphate of nickel and ammonia.*

PROPERTIES OF NICKEL.—Nickel is grey in colour, almost approaching to whiteness. It is ductile, malleable, weldable, and of great tenacity and hardness, almost equalling iron. These properties, combined with its high melting-point and its freedom from oxidation in water, have led to its use, when alloyed with other metals, as a cheap substitute for platinum for pins in artificial teeth, posts for crowns, plate for backings, bridges, etc. (See Alloys.)

In the pure state it is used as a substitute for platinum for muffles of dental furnaces, firing trays, and as a constituent of cheap dental amalgams. Nickel spatulas are better for use in mixing cements for filling purposes, as some of the finer tints are darkened if unplated steel is used for the purpose. As contained in German silver, it is used for impression trays, and in many appliances where a white metal is of advantage. Cobalt is nearly always present in commercial grades of nickel, the separation of these metals being very difficult and expensive. Commercial nickel rarely contains less than from 56 to 86 per cent. of nickel, and an analysis by Lassaigne gives a return as follows : Nickel, 73·30 ; cobalt, 22·10 ; iron, 1·0 ; alumina, 2·50 ; and silica, 0·50, plus a trace of copper (Greenwood). The metal does not readily tarnish or oxidize in air, but finely powdered, as obtained by reducing the oxide in a current of hydrogen, it is spontaneously inflammable ; and heated and immersed in oxygen it burns like iron. Nickel is magnetic at ordinary temperatures, but loses this property if heated to 250° C. It is not acted on by water, and is used as a protective coating for articles made of steel or iron, such as surgical instruments, appliances, etc., by a process of plating. Added to steel it forms an alloy, nickel steel, having a high elastic limit and offering great resistance to penetration. (See Steel Alloys.) Nickel is soluble in nitric acid, and dissolves slowly in dilute sulphuric and hydrochloric acids.

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* Newth.

ALLOYS OF NICKEL.—The chief use of nickel in industry and the arts is in its application in a valuable series of alloys, and for plating.

German Silver.—Copper, 5 parts ; nickel, 2 to 3 parts ; zinc, 3·5 parts. As in plate it contains—Copper, 5 parts ; nickel, 2 parts ; zinc, 3 parts.

For Table Cutlery.—Equal parts of nickel beyond 25 per cent. The substitution of from 2 to 3 per cent. cobalt for an equal proportion of nickel is said to improve the colour. Lead and a trace of manganese are added frequently to render the alloy more malleable.

PREPARING GERMAN SILVER.—To make German silver, fuse equal parts of nickel and copper together in crucibles ; then add balance of copper, or copper and zinc together as brass.

PROPERTIES OF GERMAN SILVER.—German silver is of a silver-white colour tinged with yellow, the colour differing with its composition. It is chiefly used as a substitute for silver, and as a base for electroplated ware. For dental purposes it has a wide range of utility, as already noted, possessing great tenacity, ductility, and malleability. In wire form it is useful, when plated, for arch wires in treating cases of malocclusion ; also in sheet form for crowns for raising bites, etc., and for fine instruments which would be attacked by acids if made of steel, such as nerve canal fillers, etc. Its electrical conductivity is low, and is not greatly affected by considerable changes in temperature. The alloy oxidizes rapidly in the mouth ; it is usually gold-plated to protect the surfaces of the teeth from contact with the metal, and is only used for temporary purposes. It may be soldered with 18-carat gold solder, although silver solder is usually employed. It should be annealed at a dull red heat for a few seconds at intervals to retain its highest degree of malleability and ductility.

German silver solder :*

Copper	50 parts.
Zinc	30 ,,
Nickel	20 ,,

Platinoid is used for much the same purposes as German silver, but possesses, if anything, greater rigidity than German silver. The presence of iron, however, limits its use, as it oxidizes readily when exposed to moisture. It does not solder so readily through oxidation of the surface (probably through the presence of tungsten or iron).

Platinoid contains—

Copper	60 parts.
Nickel	14 ,,
Zinc	24 ,,
Tungsten	2 ,,

—HIORNS.

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* Gosling, " On Crowning Teeth," p. 20.

Copper	60·50	per cent.
Nickel	15·97	,,
Zinc	23·00	,,
Lead	0·12	,,
Iron	0·35	,,
Cadmium	0·12	,,
Loss	0·04	,,

—*Ash's Quarterly*, June, 1907.

Arguzoid contains—

Copper	56·0	per cent.
Nickel	13·5	,,
Zinc	23·0	,,
Lead	3·5	,,
Tin	4·0	,,

NICKEL STEEL.—See Steel.

NICKEL-PLATING.—The solution consists of the double sulphate of nickel and ammonia dissolved in water. Ammonia is added until the solution is alkaline to blue litmus-paper. The positive pole is a sheet of pure nickel, and the article to be plated is attached to the negative pole. The plating takes any time from thirty minutes to a few hours, requiring a current of about 30 ampères, with an electromotive force of 6 volts. The solution used in nickel-plating is most unstable, the nickel showing a constant tendency to crystallize out. Water must be added to retain the strength of the solution. Steel articles to be plated are best previously plated with copper. The coating then adheres better, and there is less scaling through oxidation.

CHAPTER VI

ALUMINIUM

Symbol, Al. Atomic weight, 27·00. Specific gravity, 2·60.
Melting-point, 625° C.

OCCURRENCE.—

- Bauxite, $(Al_2Fe)O_5H_4$. The hydrated oxide associated with iron.
- Corundum, Al_2O_3. The oxide well known as an abrasive agent.
- Diaspore, $(Al_2O_3.H_2O)$. A hydrated oxide.
- Cryolite, Al_2F_66NaF. Double fluoride of sodium and aluminium.
- Cyanite, $(Al_2O_3.SiO_2)$.

Bauxite is the chief source from which aluminium is procured; it contains about one-third aluminium, together with oxide of iron, silica, oxygen, and water.

Cryolite is found in abundance in Greenland, and contains 13 per cent. of the mineral. Aluminium is never found in Nature in the metallic state, but is present in all varieties of clay (silicates of aluminium), varying in amount from 10 to 20 per cent. It also occurs in such precious stones as—

Ruby and sapphire, Al_2O_3; cyanite, $Al_2O_3SiO_2$; topaz, $Al_2SiO_4Fe_2$; garnet, $(CaMgFeMn)_3Al_2Si_3O_{12}$; kaolin or china clay, $Al_2O_32SiO_2.2H_2O$.

PREPARATION OF ALUMINIUM.—Wholer, in 1828, was the first to obtain aluminium by the decomposition of aluminium chloride, using potassium; and it is still the practice to effect the reduction by means of sodium or potassium, sodium being preferred owing to the action set up being less violent, and the cost less. The atomic weight of sodium being lower also favours the decomposition of a greater weight of aluminium.

The Deville Process.—In this process the double chloride of sodium and aluminium is used. The highest furnace heat when fuel is used is not sufficient to effect the reduction of the metal, as the combination between aluminium and oxygen is so powerful that none of the metals are able to break it up, and so set free the aluminium. The double chloride is prepared from bauxite by fusing with soda ash, then washing out the soda with hydrochloric acid, leaving a gelatinous precipitate of aluminium hydroxide. This precipitate is mixed with common salt and charcoal, rolled into balls about the size of an orange, placed in earthenware retorts, and heated to redness. Chlorine gas is passed into the retorts, and double chloride ($Al_2Cl_6 2NaCl$) distils over. The charge generally consists of 10 parts of the double chloride, 5 parts of cryolite or fluorspar, and 2 parts of sodium. This mixture is placed on the hearth of a reverberatory furnace already heated, and the doors are closed to exclude air. A violent reaction ensues, during which the charge fuses, and when it ceases it is run into moulds. The lowest layer of the mould is usually aluminium, above which is the slag of sodium chloride, with an under layer of the unreduced cryolite. The aluminium so produced has a proportion of iron and silicon present. These processes, however, are no longer employed to any great extent, preference being given to some form of electro-smelting.

Cowles Process.—The Cowles process depends upon the great heat generated by the electric arc for the reduction of the metal. A mixture of 2 parts powdered corundum and charcoal and 2 parts granulated copper or copper oxide are packed into rectangular vessels. Into the powder are led carbon rods, and the poles connected with a powerful dynamo. As the great heat generated melts the charge, the carbon rods are gradually withdrawn. The presence of copper facilitates the reduction of the aluminium, an aluminium bronze being formed.

Modern Electro-Smelting Process.—The cryolite, fluorspar, or other mineral, is reduced to a rough powder, which is packed in large boxes or furnaces around the carbon rods; these (negative and positive) are connected with a powerful dynamo. The great heat reduces the metal, which sinks and is tapped off from the bottom. Fresh ore is added, and the process is not interrupted. There are many modifications of this process, but the differences are in details. In the Hall process, for instance, the carbons are generally about forty in number, each about 3 inches in diameter and 18 inches long (Essig). As long as the carbons are in contact with the furnace charge, the resistance offered by the charge is very low; but when the aluminium is reduced, the resistance increases, which increase lights an incandescent lamp, and signals that the furnace requires recharging. The process may thus be continuous.

PROPERTIES OF ALUMINIUM.—In colour the metal is white, tinged with blue, and is capable of receiving a very high polish. It is very malleable and ductile, and these properties are considerably increased by careful annealing. Rolling increases the specific gravity from 2·60 to 2·70. Aluminium is among the lightest of the metals, and is employed for small weights. For conductivity of heat and electricity it almost equals silver. It does not oxidize in the air or sulphuretted hydrogen, and is highly sonorous, this property being influenced by the shape of the casting. Faraday points out that there are two tones present—a longitudinal and a transverse—instead of a single tone, with its corresponding upper tones, as in a bell of silver. Aluminium, being a highly electro-positive element, is capable of reducing a number of metals from combinations with oxygen and sulphur. Thus, when finely divided and heated with the oxide of manganese, chromium, tungsten, or uranium, along with lime to form a slag, an energetic action takes place: the aluminium combines with the oxygen, and the metals are obtained as a coherent mass (Newth). Use is made of this property and the high temperature reached in the welding of iron, etc. Boiling nitric acid acts on the metal slowly. Dilute nitric, sulphuric, acetic, and tartaric acids have no sensible action upon it. Hydrochloric acid is the best solvent, evolving hydrogen. Hydrates of sodium and potassium in solution readily attack the metal, evolving hydrogen. Aluminium, when cast, shows contraction on cooling. It is best cut with single-cut files. Dissolves the pins in platinum pin teeth if cast on them.

DENTAL USES.—Aluminium has been used to a certain extent as a metal for base-plates, cast dentures, impression trays; as a constituent of aluminium bronze; and for many purposes where lightness, strength, and freedom from oxidation, are essential, such as mouth-props, sections of face-pieces, etc. Its white colour, lightness, freedom from oxidation in the air or moisture, its strength, malleability, and ductility, combined with its cheapness, have encouraged the profession in its application. For base-plates, either to be struck or cast, the purer the aluminium the better it withstands the solvent action of saliva, and the more malleable it becomes, its properties generally being markedly improved. (See Casting under Pressure.)

Care should be taken to avoid contact between aluminium and the zinc and lead used as die and counter-die, as these metals exert a deleterious effect on aluminium if present even in small quantities, inducing pitting of the surface, and ultimately, by galvanic action, a gradual solution. A pickling solution of 50 per cent.

NO_3

nitric acid used before each annealing cleanses the aluminium, if contact has occurred.

To Frost Aluminium, place the metal in a solution consisting of one stick of caustic soda or potash to 4 ounces of water for three to five minutes, and pickle in 50 per cent. solution of nitric acid.*

SOLDERING OF ALUMINIUM.—The rapidity with which aluminium oxidizes at soldering temperatures, and the insoluble nature of the oxide formed, have always rendered the soldering of the metal difficult. Professor Richards holds that the solder should contain its own flux, so that the instant the solder flows the flux will clean the surface, and so make union possible. Silver chloride has also been recommended as a useful flux, the silver being deposited on the surface, and thus preventing oxidation.

The following solders are recommended :

COMMON SOLDER.

Copper	4 parts.
Aluminium	6 ,,
Zinc	90 ,,

No borax is used. Adhesion is induced by friction with small tools made of aluminium (Turner).

FOR ALUMINIUM BRONZE (TURNER).

Hard Solder.

Gold	88·88 per cent.
Silver	4·68 ,,
Copper	6·44 ,,

Medium Hard Solder.

Gold	54·40 per cent.
Silver	27·00 ,,
Copper	18·00 ,,

PLATINUM-ALUMINIUM SOLDER (SCHLOSSER).

Gold	30 parts.
Platinum	1 part.
Silver	20 parts.
Aluminium	100 ,,

GOLD-ALUMINIUM SOLDER.

Gold	50 parts.
Silver	10 ,,
Copper	10 ,,
Aluminium	20 ,,

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* *Elliot's Quarterly*, April, 1910, p. 15.

120
44.

Hard Solder for Aluminium.

Pure block tin	90 to 98 parts.
Bismuth	1 to 5 ,,
Aluminium	1 to 5 ,,

Soft Solder (Frismuth).

Pure block tin	90 to 99 parts.
Bismuth	10 to 1 ,,

Vaseline as a flux for these.

Thowles's Solder for Aluminium.

Tin	55 parts.
Zinc	23 ,,
Silver	5 ,,
Aluminium	2 ,,

The surfaces to be soldered are washed in dilute caustic alkali or cyanide solution, and dried. No flux is used.

The following are useful solders, for soldering tray-handles, etc. :

Zinc	62·50 per cent.
Tin	25·00 ,,
Lead	12·50 ,,

Paraffin wax as a flux.

—Sellons.

Cadmium	50 parts.
Zinc	20 ,,
Tin	30 ,,

Also a soft solder.

—*The Scientific American.*

Aluminium Solders.

Aluminium ..	20 parts.
Zinc	80 ,,

Aluminium	8 parts.
Zinc ..	92 ,,

Flux consists of 3 parts balsam copaiba, 1 part of Venetian turpentine, and a few drops of lemon-juice. Dip soldering-iron into mixture.

So far the soldering of aluminium for dental purposes has not proved satisfactory, and, wherever possible, it is better to reduce soldering to a minimum.

ALLOYS OF ALUMINIUM.

Tiersagent, an alloy containing two-thirds aluminium and one-third silver, used as a cheap substitute for silver, is much harder, and does not readily oxidize.

Aerdentalloy, an alloy of aluminium and silver, with aluminium greatly in excess, is used as a casting metal for base-plates, etc. (See Casting Metals.)

Aluminium Gold.—78·48 per cent. gold and 21·52 per cent. aluminium; may be struck in sheet or cast.

Aluminium Silver.—Copper, 70 parts; nickel, 23 parts; aluminium, 7 parts. An alloy said to receive a high lustre and polish, and to swage well when frequently annealed at a bright red heat.

Aluminium Tin.—100 parts aluminium, 10 parts tin. This alloy is a little heavier and whiter than aluminium, and can be welded and soldered like brass.

Aluminium combines readily with iron, the metal reducing the melting-point of iron very considerably. Iron also takes on a coating of aluminium in much the same manner as it does with tin.

Corundum and Emery.—Corundum is obtained from India, Ceylon, and several parts of America. The mineral, an oxide of aluminium, occurs in large masses and as hexagonal crystals. For grinding-wheels it is ground to powder, mixed with shellac, and pressed into moulds. Next to diamond, corundum is the hardest mineral known. Carborundum, which is still harder, is not a mineral, but is manufactured. (See Carborundum.)

Emery, an impure form of corundum, is also an oxide of aluminium. It is also obtainable in various degrees of coarseness, or in various "grits," like corundum, and is made into wheels in the same manner. It is used in the laboratory, in the powdered state, mixed with oil, for polishing metal dentures, taking a better grip of the surface than pumice, and removing scratches, file-marks, etc., more rapidly. Gummed on cloth strips, it is useful for polishing gold and amalgam fillings, and for polishing-wheel marks on artificial teeth, before putty powder is used.

Carborundum.—Carborundum, a carbide of silicon, is manufactured from coke, sand, a small quantity of common salt, and sawdust. The furnace is charged with these packed around a central core of coarse coke, and an electric current of high voltage is passed through the mixture, which results in carborundum. Near the centre of the charge the carborundum is in large irregular crystalline masses, graduating towards the sides into an amorphous powder. The various-sized crystals are separated by sifting, the larger ones broken up, mixed with shellac or some other binding agent, and made into wheels, whetstones, hones, etc. Carborundum is much harder and cuts faster than corundum or emery, having displaced these to a great extent in the dental laboratories, etc. Dilute nitric acid is used to free carborundum stones and wheels from accumulated grit.

Kaolin or China Clay ($Al_2O_3.SiO_2 + 2H_2O$), a hydrated silicate of aluminium, is the purest form of clay. It is practically infusible, and is employed in the manufacture of bodies for dental porcelains, being very refractory.

CHAPTER VII

LEAD

Symbol, Pb. Atomic weight, 206·40.
Specific gravity, 11·40. Melting-point, 327°C.

OCCURRENCE.—Galena (PbS), the natural sulphide, is the chief source of the metal.

White lead ore, or cerusite ($PbCO_3$), the carbonate, is also an important source of the metal.

Anglesite ($PbSO_4$), lanarkite ($PbSO_4.PbO$), matlockite ($PbCl_2PbO$), pyromorphite ($3Pb_3.P_2O_8PbCl_2$), are other sources.

The natural sulphide and carbonate are the most abundant sources of the metal for commercial purposes. Galena generally contains traces of silver, and is treated specially for the extraction of silver, even when the silver is as low as 2 parts per 1,000 of lead. The ore generally contains about 87 per cent. lead and 13 per cent. sulphur. Antimony is the chief impurity present as the sulphide of the metal. The carbonate, less abundant than the sulphide, is generally reduced with galena, and usually contains close on 78 per cent. of lead; it also contains traces of silver, chiefly as the chloride, iodide, and native silver.

PREPARATION OF LEAD.—There are three main processes: 1. **The Air Reduction Process.**—In this the galena is roasted to such an extent that part of the sulphide is changed to the oxide and sulphate, so that there are present definite proportions of each. The temperature is increased, and the sulphate and oxide react upon the unchanged sulphide ; metallic lead is reduced, and sulphur dioxide given off.

2. **Roasting and Carbon Reduction Process.**—The galena is roasted until it is almost entirely decomposed or converted to lead oxide, with a trace of lead sulphate. It is then reduced by heating with carbon ; or the sulphate is converted to lead silicate by melting it with silica after the roasting process is completed, the silicate being then reduced to the metallic state by scrap iron.

3. **Iron Reduction Process.**—The galena is melted with scrap iron ; the iron combines with the sulphur, lead is set free, and a compound of the sulphide of iron and lead is produced.

The American Air-Cooled Hearth and the **Scotch Ore Hearth** processes consist in melting the lead in a rectangular cavity, the bottom and the sides of which are of cast iron. The front is generally composed of bone ash and crushed galena, this mixture being impervious to metallic lead, and is sloped to carry off the molten lead. Over the hearth are hoods to carry off the lead fumes. The ore is melted, and a blast of cooled air is passed over the molten lead, which is drawn off into iron pots. The blast carries off certain proportions of lead and lead sulphate, the term " lead fumes " being applied to these, which are condensed by passing through long flues or wide chimneys kept cool with circulating water. The escaping lead is deposited as a dust, and is collected and reduced.

In the blast-furnace process the essential features are similar. Against the ore hearth processes, it is held that the workmen are more exposed to the poisonous fumes than in the other processes, and that there is a greater loss of lead through volatilization. The cooler the blast of air, the less is the loss through this cause. The lead from all these processes has generally to be " softened," which consists in remelting to oxidize such metals as antimony, copper, zinc, etc., which rise to the surface, and are removed as a floating scum. The silver is removed by a special series of processes. (See Desilverizing of Lead.)

DESILVERIZING OF LEAD.—There are three main processes: 1. **Pattison Process.**—This process is based upon the fact that, if there are present 800 ounces of silver to the ton of lead, the two metals form a eutectic alloy, and, on cooling from the molten state, show no tendency to separate or liquate. When less silver or more is present, however, the two metals disclose a constant tendency to separate. Advantage is taken of this property, the silver being seldom in excess of 500 ounces to the ton of lead. The argentiferous lead is melted, and cold water sprayed over it, which causes the crystals of pure lead to form on the surface. These are then ladled out, and remelted in a second pot. The process is continued through five or six pots, until pure lead is obtained at one end of the series, and the concentrated silver and lead alloy at the other. The silver is recovered by cupellation. (See Gold.)

2. **Luce-Rozan Process.**—This is considered to be an advance on the Pattison process, hand labour being done away with in the stirring, cooling, and ladling of the lead. The apparatus consists of two pots, one at a higher level than the other. The lead is melted in the higher, and jets of water and steam are played upon it, to hasten the crystallizing of the lead. This cooling is continued until two-thirds of the charge has crystallized, and the remaining liquid third is then drained off through pipes controlled by valves, the crystals being retained by means of perforated plates, into the lower pot. In this process subsequent softening of the lead is unnecessary, as the steam, the stirring, and the disturbance of the molten metal, cause such impurities as are present to rise to the surface as a scum, when they are ladled off.

3. **Parkes Process.**—This process depends upon the recognized tendency of gold and silver to alloy with zinc in preference to lead, if both metals are present in the alloy, and also on the fact that lead and zinc, if alloyed, tend to separate on cooling. Zinc is added to the lead to the extent of 1½ per cent. for every 50 ounces of silver present per ton, the whole charge thoroughly melted, stirred, and allowed to cool. The silver combines with the zinc and crystallizes on the surface, and is ladled off into another pot, where the process is repeated. The zinc, highly charged with silver, is finally transferred to a retort, with a little charcoal, and distilled, when the zinc is volatilized and afterwards condensed, leaving the silver in the retort.

PROPERTIES OF LEAD.—Lead is a bluish-grey metal, possessing a bright metallic lustre when freshly cut; this lustre becomes quickly dimmed by the superficial oxidation of the metal in contact with air. It ranks amongst the softest of the metals, and can be readily cut into slices, to which property the term "sectile" is applied. It is readily marked by swaging, and quickly receives impressions. It is malleable and ductile, but its tenacity is very low, and it can only be drawn into thin wire with difficulty. The metal can be welded, and applied to paper leaves a grey mark. When struck, it emits the proverbial dull sound, but is slightly sonorous if cast in mushroom shape and struck. Lead may be readily deposited from a solution of the acetate by zinc or electricity. Its conductivity is very low; it has no taste, but possesses a peculiar odour when freshly cut. Commercial lead, either in ingot or sheet, is fairly pure, the percentage of such metals as silver, iron, tin, antimony, arsenic, etc., being extremely small. Antimony and arsenic harden the metal when present in small quantities, and copper and silver tend to increase the sonorousness.

Lead exhibits a strong affinity for silver, and, besides being found in many ores of silver, the action between the metals is somewhat peculiar. Lead is used in the cupellation process in the parting of gold and silver, advantage in this process being taken of its affinity for oxygen. In his book* Sir W. Roberts-Austin alludes to this in the introductory historical sketch.

Biringuecio, a contemporary of Paracelsus and Agricola, remarks, " If we had not lead, we should search in vain for precious metals, for without its aid we could not extract gold or silver from stones containing them "; thus showing that it was known that lead was capable of reducing metallic oxides, and liberating the gold and silver from other metals combined with them as impurities. Lead exhibits the property of " flow " to a remarkable extent, even when subjected to pressure in the solid state. Advantage is taken of this in the making of lead piping. The lead is driven under pressure through steel moulds, by this means insuring a homogeneous piping, and one which can be made of indefinite length.

LEAD AND OXYGEN.—The metal combines with oxygen in several proportions, yielding plumbous and plumbic oxides, plumbic peroxide, and combinations of these three. Of these, plumbic oxide, also known as " massicot " or " litharge," is the most important, as it is this compound which, by dissolving metallic oxides, gives lead so prominent a place in metallurgy.

DENTAL USES OF LEAD.—Its most important use is as a counter-die in swaging base-plates ; its low melting-point, softness, cheapness, and the numerous meltings it will withstand without alteration of its properties, make it valuable for the purpose. It is also a constituent of lead shot used in swaging, of the soft or tin solders (see Tin), and as centres for polishing-brushes, etc. In swaging gold, using a counter-die of lead, wash-leather or several layers of paper should be used to keep the gold from coming in contact with lead, as the metal has a powerful effect in rendering gold friable and brittle ; less than 1 part lead in 1,000 parts gold makes the gold too brittle to swage.

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* " Introduction to the Study of Metallurgy."

Lead in the mouth is poisonous, and is not contained in dental amalgams, alloys for bases, etc. Traces of lead are present in some makes of aluminium bronze, the lead facilitating rolling ; also in sheet brass and German silver. Lead enters into the composition of many of the fusible metals, as Wood's, Rose's, Lichtenberg's, and Newton's. (See Fusible Metals.)

ALLOYS OF LEAD.

Lead and Arsenic : Lead Shot.—Combined with arsenic, which hardens lead, and makes it brittle if in excess, it is used as lead shot for swaging purposes, in making crowns and base-plates. Lead shot is of advantage where Babbit metal or any of the other die metal alloys are employed, as it removes the chances of the die being damaged by having hot metal poured over it.

Lead and Antimony.—In some works antimony is added to lead in the making of lead shot, the metal having a hardening effect on the lead. The metal is also added to lead in type metal. For large type from $\frac{1}{8}$ to $\frac{1}{4}$ per cent. of antimony is added ; for small type tin is added, and in other forms copper and iron. The alloy of lead, antimony, and tin, or that of lead and tin, is used as counter-die metals, the hardening effect of the antimony and tin helping to overcome any tendency towards change of shape during swaging. In the lead and antimony alloys there is considerable waste through oxidation.

Lead and Tin.—Besides the alloy already given for swaging purposes, lead and tin enter into the composition of soft solders, the proportions of the metals varying according to the purposes for which the solders are intended.

EXAMPLES.—Fine solder contains 1 part lead to 2 parts tin (as for dental use).

Soft or common solder contains equal parts of lead and tin (tinsmith's solder).

Plumber's solder contains 2 parts lead and 1 part tin (for jointing lead).

Lead and Mercury.—These may be alloyed by rubbing in the mercury, but the alloy possesses no valuable property.

CHAPTER VIII

SILVER

Symbol, Ag. Atomic weight, 107·93.
Specific gravity, 10·53. Melting-point, 950° C.

OCCURRENCE—Native Silver.—Silver is occasionally found native in masses weighing several hundredweights. It usually contains gold, copper, mercury, and other metals; is always present in native gold; is found combined with chlorine, bromine, iodine, and sulphur, and of a silver-white colour in laminated or filamentous masses; also in cubes, crystals, or grains.

The following may be regarded as the more important natural compounds of silver:

Name.	Formula.	Percentage of Silver.
Argentite, or silver glance ..	Ag_2S	87
Kerargyrite, or horn silver	$AgCl$	75
Pyrargyrite, or ruby silver ore	$3Ag_2S.Sb_2S_3$	60
Proustite, or light red silver ore	$3Ag_2S.As_2S_3$	65·5
Stephanite, or brittle silver ore	$5Ag_2S.Sb_2S_3$	68·5
Polybasite	$9(Ag_2Cu)S.(SbAs)_2S_3$	
Stromeyerite	$Ag_2S.Cu_2S$	
Hessite	Ag_2Te	
Fahlore, or grey silver ore	$4(Ag_2Hg.CuFeZn)S.(SbAs)_2S_3$	
Embolite	$Ag(ClBr)$	

PREPARATION OF SILVER.—The processes for the reduction of silver from the ore are somewhat numerous and varied, and the process selected depends upon the form of combination in which the silver is present. They may, however, be divided into three classes, as follows :

1. **Amalgamation with Mercury.**—This process is based upon the solubility of silver in mercury, and the readiness with which the mercury can be driven off by heat.

2. **The Lead Methods.**—These processes depend on the readiness with which silver and lead combine, the lead being separated after the extraction of the silver from the ore by cupellation.

3. **The Wet Methods.**—In these processes the silver is extracted from its sulphides by first converting them into sulphates or chlorides, then washing them out with water or a solution of common salt, and depositing the silver from this solution.

1. **Amalgamation Methods.**—The ores best adapted for treatment by this process are comparatively free from base metals, and known as *milling ores*. There are three methods—the Mexican method of amalgamation heaps ; the European method of amalgamation in casks, known as the " barrel process "; and the amalgamation in kettles and pans.

The Mexican Method.—This process depends upon the solubility of silver in mercury, and the power of the mercury to decompose certain compounds of silver by forming a solution from which the silver can afterwards be extracted. The ores are picked free of any portions containing chlorides, bromides, or iodides, of native silver, which, being the richest, are reduced separately. The ores are then picked free of the ore too poor to repay treatment, washed and placed in tanks or pits, and reduced to powder by crushing. The powdered ore is dried and piled in heaps on a concentrate floor covered with from 3 to 5 per cent. common salt, and mixed by mules treading upon it. This is continued for the greater part of one day; mercury is added, with 1 to 2 per cent. of roasted copper pyrites, known as *magistral*, and stirred at intervals for several days. The chemical action taking place is complex, but may be represented thus:

$$CuSO_4 + 2NaCl = CuCl_2 + Na_2SO_4.$$
$$2CuCl_2 + Ag_2S = 2AgCl + Cu_2Cl_2 + S.$$
$$Ag_2S + Cu_2Cl_2 = 2AgCl + Cu_2S.$$

The silver chloride dissolves in the sodium chloride, and is reduced by mercury, mercurous chloride being formed, which passes off with the water—

$$2AgCl + 2Hg = Hg_2Cl_2 + 2Ag.$$
$$Hg_2Cl_2 + Cu = CuCl_2 + 2Hg.$$

The mass is transferred to stone vats, and water and mercury added, the water carrying off adhering particles of minerals and mercuric chloride. The excess of mercury is removed by straining the amalgam through canvas bags, and the silver residue is freed from the mercury by sublimation.

Amalgamation in Barrels—*The Freiburg Process*.—This process is most suitable for the treatment of rich sulphide ores, or such as contain sulphides of iron, antimony, bismuth, etc. Iron pyrites is added to bring it up to 25 per cent., and 10 per cent. common salt is added. The mixture is roasted in a reverberatory furnace to drive off arsenic, some of the sulphides, etc. The roasted mass is reduced to a powder, placed in barrels partly filled with warm water, and the barrels caused to revolve. The action may be expressed thus:

$$2AgCl + Fe = 2Ag + FeCl_2.$$

Mercury and a little copper sulphate are added, and as the amalgam settles it is drawn off.

This process is held to entail no greater loss than 9 per cent. of the silver in the ore, compared with 12 to 25 per cent. in the Mexican method.

Amalgamation in Kettles.—Known as the *hot method.* The ores are reduced in kettles made with copper bases. As in the other processes, the ore is reduced to powder, and is converted into the chloride by adding common salt and mercury; water is added, and the mixture heated to the boiling-point. The copper of the kettle induces the deposition of the silver dissolved out by the mercury, and the mercury is expelled by distillation.

2. **Lead Methods.**—In these processes the silver is concentrated in lead, and separated by cupellation; or the ore is melted with ores of iron, lead, or copper, and the products cupelled. (See Pattison and Parkes Processes under Lead.)

3. **Wet Methods.**—These processes are based upon the conversion of the insoluble silver compounds into a soluble form, and precipitation of the silver by means of another metal, such as copper; or precipitating it as the readily decomposed sulphide.

The Ziervogel Method.—In this the ore is roasted to convert the copper and iron into insoluble oxides, while the silver as the soluble sulphate is removed with warm water, and deposited by means of scrap copper.

Percy-Patera Method.—In this the ore is roasted with common salt, forming silver chloride, which is extracted by adding sodium thiosulphate. To this solution sodium or calcium sulphide is added, precipitating silver sulphide. The silver is obtained by roasting the sulphide in a reverberatory furnace.

Russel Method.—In the Percy-Patera process any lead sulphate present is deposited with silver as lead sulphide, and to obviate this, sodium carbonate is added to the solution, after the solution of the chloride in sodium thiosulphate. This deposits as insoluble carbonates any lead, zinc, iron, or manganese, present. The liquid containing the silver and copper in solution is then treated as in the Percy-Patera process.

Electro-Metallurgical Processes.—These processes are confined to the extraction of silver from alloys in the wet methods, the silver being recovered from the slimes left after the removal of the other metal or metals. In some works where lead is produced, the silver is concentrated in lead, and afterwards cupelled. In the Mœbins process the dried slimes are melted and cast into anode plates, the cathodes are copper, and the electrolyte is either an acid solution of copper nitrate or copper sulphate. A current of low tension transfers copper from the anode to the cathode; silver, gold, and platinum, come down as a mud. This mud is collected and parted electrolytically.

REFINING OF SILVER.—The silver produced by these processes has generally to undergo refining to bring it to the standard of "fine silver." The means adopted is generally some form of cupellation process, as described under Gold. In these the idea is to concentrate the silver in a mass of lead, and keep the alloy melted until the lead has oxidized into litharge, and passed into the bone ash body of the cupel. The silver is then dissolved in nitric acid, common salt added to form the chloride, the chloride washed and placed in a dilute solution of hydrochloric acid, and silver deposited by means of sheets of clean malleable iron. Or the chloride may be placed in a dilute solution of sulphuric acid, and the silver deposited by sheets of clean zinc. The silver thus produced generally ranks as 999 parts pure in 1,000, the trace of impurity being copper or iron.

PROPERTIES OF SILVER.—Silver is remarkable for its whiteness, and, although iridium is also white, its colour in comparison is much inferior. Silver possesses a brilliant metallic lustre, and is only exceeded in malleability and ductility by gold, having been reduced to foil $\frac{1}{10,000}$ inch in thickness. For swaging purposes, and for being drawn into wire, the metal requires more frequent annealing than gold; otherwise it discloses a tendency to become brittle. In hardness it occupies a position midway between gold and copper, the degree of hardness being influenced by the presence of impurities. A single grain of pure silver has been drawn into wire 400 feet long,* and the tenacity of the metal is given as 7·1 tons per square inch. The specific gravity of silver may be increased from 10·53 to 10·57 by hammering or rolling. Silver is the best conductor of heat and electricity, but the presence of impurities has a very marked effect upon the conductivity. The metal melts at a white heat (950° C.), is volatilized at a high temperature, and when heated in the oxyhydrogen flame the vapour given off is of a pale blue colour, inclining to purple.

The blackened appearance of silver articles after exposure to air is not due to oxidation in the ordinary sense, but rather to a coating of the sulphide formed by the action of the sulphuretted hydrogen of the air. This blackening is also specially remarked in amalgam fillings containing a large percentage of silver. Silver occludes oxygen freely, absorbing twenty-two times its volume of oxygen when in the molten state, but yielding the gas as it becomes solid, the surface rising into protuberances or small craters, each giving out oxygen when it bursts. The phenomenon is referred to as the "spitting" or "vegetation" of silver. The addition of small quantities of copper to silver for casting purposes overcomes this spitting, which tends to destroy the surface of the castings. By covering the molten metal with a layer of common salt, 3 or 4 inches in thickness, the metal sets with a clean, bright, and smooth surface, the salt reducing the occlusion of oxygen, and so preventing the spitting. When heated to redness, silver occludes 0·545 its volume of oxygen. Dr. Percy states that silver alloyed with one-third its weight of gold still occludes gases and spits on setting; but as the gold

* Percy's "Metallurgy."

is increased beyond this, the occlusion and spitting are reduced and disappear.

Silver decomposes sulphuretted hydrogen at ordinary temperatures, the metal being covered with a layer of argentic sulphide. Use is made of this property in "oxidizing" silver articles, the articles being boiled in a solution of potassium sulphide until the desired shade of darkening is reached. Silver combines with bromine, chlorine, and iodine, at ordinary temperatures, the bromide, chloride, and iodide, being formed. Nitric acid is the best solvent of the metal, silver nitrate being formed and oxides of nitrogen given off.

Dilute sulphuric acid has practically no action on the metal, but strong sulphuric acid is decomposed when heated with silver, giving off hydrogen and sulphur dioxide, and forming silver sulphate. Advantage is taken of the action of the acids in parting silver from gold, the gold being insoluble in either of the acids. (See Sulphuric Acid Process—Gold.)

$$2Ag + 2H_2SO_4 = Ag_2SO_4 + 2H_2O + SO_2.$$

The Dental Uses for Silver are many. In the pure state in wire form, it is used for sutures in fractures of the maxillæ, and in cases of malocclusion, etc., the softness of the metal and its clearness when in contact with raw tissue or mucous membrane being appreciated. Pure silver in the form of cylinders is used for expressing surplus mercury from fillings by absorption—a little less rapidly than gold cylinders. It is the use of the metal when alloyed that is most important, such as the alloy with gold, platinum, copper, tin, aluminium, zinc, and the groups of alloys used as dental amalgams.

ALLOYS OF SILVER.

In the pure state silver is too soft for commercial purposes. British silver coinage contains 75 parts copper per 1,000 parts pure silver ; Continental silver coinage, 100 parts copper per 1,000 parts pure silver. Mexican dollars contain 337·14 grains pure silver to 40·65 grains pure copper ; United States dollars contain 371·25 grains pure silver and 41·25 grains pure copper.* Coin or " standard " silver is generally pure silver plus 10 per cent. copper.

Silver and Gold.—The metals alloy freely, but do not appear to enter into chemical combination. Gold is frequently added to silver alloys to reduce the tendency to oxidation of the surface by the formation of the sulphide ; but as a rule silver is added to gold, and is detailed under Alloys of Gold.

Silver and Platinum.—These metals alloy freely, the resulting alloys being of a white colour, though duller than silver.

Dental Alloy contains from 3 to 10 grains of platinum per pennyweight of silver. The alloy is used for base-plates, backings, clasps, pivot-posts, strengtheners, etc., as a cheap substitute for gold. In colour it is white, is less liable to oxidation than silver, is harder, stronger, and possesses greater elasticity. The fusing-point is high, permitting the use of 16 and 18 carat gold solder. The use of silver solder with this alloy is not to be recommended, as, although the silver solder more readily approaches the colour of the alloy, it oxidizes rapidly, becoming almost black. The proportions of platinum in the alloy are subject to great variations, ranging in some samples from as low as 10 and 12 per cent. to over 25 per cent., as in that supplied for pivot-posts. The alloying of silver and platinum is readily accomplished if the silver is brought to fusing-point and the platinum added as foil or thin ribbons, the silver absorbing the platinum. The metals do not disclose any distinct tendency to liquate, and after being gently stirred the alloy may be run into ingots and allowed to set. The best results are obtained in annealing if the alloy be kept at a bright red heat for a few seconds before cooling.

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* Turner's " Phosthetic Dentistry "

Von Eckart's Alloy, used in France for the same purposes as dental alloy, contains silver, 3·53 ; platinum, 2·40 ; copper, 11·71.[*] It is very elastic, white in colour, and takes a high polish.

Silver and Copper.—Copper added to fine silver increases the hardness, tenacity, and strength. The hardest alloy of the two metals contains 1 part copper to 4 parts silver. Copper, unless added in greater proportions than 40 to 50 per cent., does not alter the colour of the silver ; and if added above this proportion, the alloy tends to liquate. Levol's homogeneous alloy, containing 718·93 parts silver per 1,000 parts alloy, does not tend to liquate. The density of silver and copper alloys is less than the mean density of the metals present, owing, it is held, to expansion occurring as they combine.

Silver and Zinc.—These metals exhibit a decided affinity for each other, and alloy readily. Zinc is seldom added alone to silver, but generally as a constituent of brass, as in silver solder.

Silver and Mercury.—These metals also exhibit a decided affinity, mercury, if present in sufficient quantities, dissolving silver, as has been described under the Amalgamation Processes for the extraction of silver. The two metals are seldom, if ever, amalgamated, for dental purposes, the silver being alloyed with tin, gold, platinum, etc. (See Dental Amalgams.)

Silver Solders.—These are generally composed of fine silver or standard silver plus brass or copper and brass. "Standard silver" alone makes a high-grade solder for the better qualities of German silver and brass, or 6 parts standard silver plus 1 part brass does well for the same purpose. The best-known silver solders contain—

[*] Essig and Koenig, p. 207.

No. 1.*

Fine silver	66 parts.
,, copper	30 ,,
,, zinc	10 ,,

No. 2.*

Fine silver	6 parts.
,, copper	2 ,,
,, brass	1 part.

No. 3.

Fine silver	4 parts.
,, brass	3 ,,

No. 4.

Fine silver	20 parts.
,, brass	10 ,,
,, zinc	5 ,,
,, copper	1 part.

No. 5.

Fine silver	4 parts.
,, brass	2 ,,
,, zinc	1 part.

No. 6.

Silver coin	9 parts.
Zinc	1 part.

The same rule applies to the soldering with silver solder as applies to a gold solder—namely, that it should be chosen with a lower fusing-point than the article to be soldered. Borax acts as a good flux for use with these solders. not used

4 imp

ELECTRO-DEPOSITION OF SILVER.—The bath is of double cyanide of silver and potassium. The silver cyanide is prepared by depositing silver from a solution of silver, using nitric acid and cyanide of potassium, which precipitate is soluble in excess of potassium cyanide. To facilitate the plating the metal is coated with a thin layer of phosphorus, the phosphorus reducing the silver nitrate more readily. Or the articles to be plated, after being washed in dilute nitric acid or aqua fortis, are dipped in a solution of nitrate of mercury until they are coated with a thin layer of mercury. The positive pole is connected with a series of silver plates, while the article to be plated is connected with the negative. Iron and zinc articles are benefited by a previous plating of copper or a coating of bronze, the silver adhering better, and showing less tendency to chip.

DRY SILVERING.—The process known as "dry silvering" consists in applying an amalgam of silver to a clean surface of metal, and heating to expel the mercury. Another process consists in making the surface of the metal thoroughly clean by using aqua fortis and pumice ; the surface is roughened with a graver, so that the silver-foil may adhere to it. The metal is then heated until a thin blue film of oxide forms on the surface, when the silver-foil is tightly burnished to place, the heating being repeated before each layer of the foil is applied.

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* Richardson's "Mechanical Dentistry."

CHAPTER IX

COPPER

Symbol, Cu.	Atomic weight, 63·2.
Specific gravity, 8·82.	Melting-point, 1,050° C.

OCCURRENCE—

Name.	Composition.	Copper in 100 Parts of Pure Ore.*
Red copper ore, cuprite, or ruby copper	Copper, oxygen—Cu_2O	89
Black oxide, or melaconite	Copper, oxygen—CuO	80
Copper glance	Copper, sulphur—Cu_2S	80
Indigo copper	Copper, sulphur	69
Purple copper ore	Copper, iron, sulphur	variable
Copper pyrites, or chalcopyrite	Copper, iron, sulphur—$Cu_2SFe_2S_3$	35
Peacock copper	Copper, iron, sulphur—$3Cu_2SFe_2S_3$	56
Grey copper ore	Copper, sulphur, iron, antimony, arsenic	variable
Malachite, or green carbonate	Copper, oxygen, carbonic acid, water—$CuCO_3.Cu(OH)_2$	58
Blue malachite, azurite, or blue carbonate	Copper, oxygen, carbonic acid, water—$2CuCO_3.Cu(HO)_2$	55
Chrysocolla (silicate of copper)	$CuO.SiO_2 2H_2O$	—

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* Huntingdon and Macmillan.

Of these ores, copper pyrites (or yellow copper ore) is the most abundant, and probably copper glance is next in importance. Copper is also found in the metallic state in several parts of the world, the Lake Superior mines being the best known.

PREPARATION OF COPPER.—The method by which the copper is extracted from the ores will vary according to the ore treated. Thus, where the ore contains no sulphur—namely, oxides and carbonates—copper is obtained by the simple process of smelting the ore in a blast-furnace with coal or coke. Where mixed ores, especially when with sulphides, are present, the processes become more complex, of which the following is given briefly :

The Welsh Process for copper-smelting generally consists of six stages, the ores containing on an average 13 per cent. copper and 30 per cent. iron.

1. The ore is roasted or calcined at a dull red heat for twelve hours, to expel arsenic and part of the sulphur, and partly oxidize the metals present. A reverberatory furnace is used, and ores broken into rough pieces.

2. The roasted or calcined ore is melted. Copper oxides present react upon a portion of the ferrous sulphide, forming cuprous sulphide and ferrous oxide, The ferrous oxide is carried off in the slag (formed from the silicate present in the ores or from the slag of the fourth process), leaving what is known as *coarse metal*, containing about 35 per cent. copper. By pouring this *coarse metal* into water it is granulated and prepared for the third stage.

3. The coarse metal is calcined, to convert more of the remaining sulphide of iron into oxide. The roasting is generally carried on for twenty-four hours, the coarse metal being kept at a dull red heat.

4. Coarse metal from the third stage is melted with some of the slag from the sixth stage. Most of the remaining iron is carried off in the slag, leaving behind

a regulus of copper, known as *fine* or *white metal*, containing from 60 to 75 per cent. of the metal as cuprous sulphide.

5. The fine metal is roasted from twelve to thirty-six hours to drive off more sulphur; part of the cuprous sulphide is converted to cuprous oxide, and the remaining ferrous sulphide to ferrous oxide. The copper after this roasting is known as *blister copper*, so called from its appearance.

6. *The Refining Process.*—The copper from the fifth stage is melted upon the hearth of a reverberatory furnace in an oxidizing atmosphere. Iron, arsenic, lead, etc., if present, are first to oxidize, the sulphides passing off as sulphurous acid, the oxides volatilizing or combining with the siliceous lining of the surface to form a slag. The copper itself then begins to oxidize, this oxide reacting upon any sulphide present, with the evolution of sulphur dioxide and the reduction of copper. The metal is now covered with a layer of wood charcoal or anthracite, and stirred with a pole of young wood (birch usually), this stirring being known as *poling*, which still further reduces any copper oxide present. The *poling* is continued until samples show the copper with a close grain, a silky fracture, malleable, and of a light red colour.

Blast-Furnace Process.—Blast-furnaces are sometimes employed to produce a crude metallic copper, known as *black copper*, direct from oxidized ores of copper, but more frequently to concentrate the copper in matts from which it may afterwards be recovered. The furnace charge generally consists of about 30 per cent. of copper, with balance of silica, sulphur, and iron, from the slag of a previous smelting. The copper is raised by this process to about 50 per cent., and the Bessemer or Welsh process, or some modification, is employed for the refining.

Bessemer Process for Copper Matts.—Converter very similar to that employed for steel, only twyers are higher up, away from bottom of the furnace. Charge consists of matts containing between 50 and 60 per cent. copper. As in the process for steel, the converter is heated, and receives the charge in the molten state. The blast is turned on, and, as the reduction proceeds, the slag containing most of the oxidized impurities is canted off. The reaction is not so violent as with steel, the flames are not markedly vivid, and the end of the process is reached when the little sparks of copper given off from the fused charge are seen to rebound from the sides of the converter. It is claimed that a 99 per cent. copper can be produced in this way.

Electrolytic Refining of Copper.—This process is chiefly employed for refining copper, or for extracting copper when gold and silver are combined. The sulphate or chloride of copper is the solution or electrolyte. If copper regulus is used, it is cast into slabs, which are suspended in a row and connected with the positive pole. Between each slab is hung a thin sheet of copper, each connected with the negative pole. It is upon these thin sheets that the fine copper deposits. Or the first slab or plate is connected with the positive pole alone, and the cathode a slab of pure copper. By this means each copper slab after the first acts as cathode to the slab behind it, and anode to that in front, the copper being deposited from plate to plate until all is dissolved.

Such metals as platinum, gold, silver, lead, and slag, are not dissolved in the solution, and are left as a slimy deposit on the anode. The electromotive force is usually about 0·3 volt between each pair of plates placed in series, and the last plate, being of pure copper, conducts the current back to the positive pole of the dynamo. Another wet process consists in depositing copper from blue stone, the crude commercial sulphate. The sulphate is brought to solution, and the copper reduced to the metallic state by means of zinc or iron plates suspended in the solution. The copper thus reduced is not chemically pure, and has to be washed in dilute sulphuric acid. (See Preparation of Copper Amalgam.)

PROPERTIES OF COPPER.—The melting-point of copper is 1,050° C. The specific gravity of freshly cast pure copper is 8·82, which can be increased to 8·90 by rolling. In colour copper is light red, and exhibits a salmon colour and a fine silky structure on fracture after rolling. Copper on solidifying presents a vesicular structure, by which the density of the metal is greatly diminished. This may be accounted for by the readiness with which copper occludes oxygen when in the fused state, and the effort of the enclosed gas to escape as the metal solidifies is probably the cause of the cavities or spaces. These are removed by hammering or rolling, bringing the molecular structure into closer apposition ; hence the increase of specific gravity. Copper ranks next to silver in its power of conducting heat and electricity, which property is powerfully influenced by impurities, such as antimony, arsenic, bismuth, and nickel. Silver and gold are among the best conductors, yet either of these alloyed with copper reduces the conductivity of the metal.

Copper expands on solidifying ; is not volatilized at ordinary furnace temperatures, requiring the oxy-hydrogen blowpipe flame to effect this. The metal oxidizes at ordinary temperatures, and very rapidly at a red heat. In moist air, in the presence of CO_2, it becomes coated with green copper carbonate, or *verdigris.* Copper is passive to strong nitric acid, but diluted there is a violent reaction, and nitric oxide is evolved. Hot sulphuric acid, either strong or diluted, attacks the metal, sulphur dioxide is evolved, and copper sulphate formed. Iron and zinc deposit copper from solution. The metal is also deposited from solutions of the chloride and sulphate by electricity.

It unites with oxygen in two proportions, forming cuprous oxide (Cu_2O) and cupric oxide (CuO).

Commercial copper generally contains traces of antimony, arsenic, bismuth, iron, tin, and sulphur. Lead is added to sheet copper to facilitate rolling. For electric installations and conducting purposes the purest forms are generally employed, and known as "best selected." The Lake Superior copper is among the purest grades for this purpose.

ALLOYS OF COPPER.

Gold and Copper unite in all proportions, the chief use being to harden the gold, reduce the carat, and minimize the whitening effect of the silver in various carats. (See Gold.)

Silver and Copper unite in all proportions, the action being similar to that of gold; the purity is reduced, the silver is hardened. Coin silver and silver for art purposes contain traces of copper, advantage being taken of its hardening effect.

Platinum and Copper alloy only at a very high temperature. Copper is added to platinum only as a vehicle for adding other metals, such as gold in the gold and platinum alloys for fillings, bands, porcelain inlay matrices, etc. (See Alloys of Gold.) Platinum and copper alloys resemble gold in colour very closely, and also in their specific gravities.

Mercury and Copper amalgamate freely. (See Copper Amalgam.)

Zinc and Copper alloy readily, the alloy of these being known as "brass."

Nickel and Copper alloy in all proportions, and alloys are employed in the manufacture of the different grades of German silver. (See Nickel.)

White Metal contains copper and zinc, the latter in excess—the greater the percentage of zinc, the whiter the alloy—and is chiefly used for art purposes. Zn.

Brass.—An alloy of zinc and copper. Ordinary brass contains from 30 to 40 per cent. zinc, and can be rolled or hammered without fracture or tear, cold or hot; with zinc 60 to 70 per cent. yields an alloy brittle and unworkable. Sheet brass of a good quality contains copper 70 per cent., and zinc about 30 per cent., with a trace of lead to facilitate rolling. Brass for casting frequently contains 50 per cent. zinc, 3 per cent. tin and lead, 47 per cent. copper. Brass was formerly used to a certain extent as a die metal in metal-work, but its high melting-point, contraction of the casts, the marked tendency of the alloy to liquate, and the deterioration after several heatings, have led to its disuse. The resemblance between gold and many of the alloys of copper in respect to colour have led to the use of these for objects of art, and, in the case of aluminium bronze, as a base for dentures, crowns, etc.

Pinchbeck contains copper 90 per cent. and zinc 10 per cent.

Dutch metal contains copper 84·6 per cent. and zinc 15·6 per cent.

Muntz metal contains copper 60 to 64 per cent. and zinc 36 to 40 per cent.

Mannheim gold contains copper 75 per cent. and zinc 25 per cent.

Mosaic gold contains copper 50 per cent. and zinc 50 per cent.

Aich's metal contains copper 60 per cent., iron 1·8 per cent., and zinc 38·2 per cent.

Sterro metal contains copper 55 to 70 per cent., zinc 34 to 44 per cent., iron 1 to 2 per cent., tin 1 to 2 per cent.

Bronzes.—These alloys generally contain copper and tin.

Gun-metal contains copper 90 per cent. and tin 10 per cent.

Bell-metal contains copper 80 per cent. and tin 20 per cent.

Speculum metal contains copper 67 per cent. and tin 33 per cent.

Tin added to copper has a hardening effect, as witness speculum metal; but if in excess the alloy is first brittle, and if tin is further increased it becomes soft. An alloy of copper and tin containing 18 per cent. tin has a tenacity of 17 tons per square inch.*

Phosphur Bronze.—Phosphorus added to copper has a hardening effect, imparting toughness, hardness, and elasticity, and is present in bronzes generally. The phosphorus may be added when the copper is molten, or in the form of the phosphide of tin (phosphor tin), the alloy generally containing from 0·25 to 3 per cent. phosphorus, and 5 to 15 per cent. tin, and the remainder copper.

Tin phosphide alloys perfectly with copper, forming a homogeneous alloy, which is added in small quantities to the copper for the sheathing of ships, to help to overcome the corrosion of the metal by the sea-water. Industrially it is used for bearings of machinery, on account of its wear-resisting properties. Its tenacity is almost equal to mild steel, with the advantage that it yields more before fracturing.

Arsenic added to copper in the proportion of 1 to 10 yields a white malleable alloy, which is used for faces of watches, clocks, barometers, thermometers, etc., owing to its colour, hardness, and because it does not readily discolour in air.

Aluminium Bronze contains 90 to 95 per cent. copper and 5 to 10 per cent. aluminium. This yields an alloy which must be remelted several times before it becomes homogeneous. In colour it resembles 12 to 20 carat gold, the colour varying with the proportions of copper—a fact which has led to its use for base-plates, and in the dental hospitals for crowns, backings for pivots, regulating appliances, and almost any purpose to which gold can be applied. In sheet form it is not readily oxidized in air or when in the mouth. The melting-point is about 1,700° F.; specific gravity, 7·68. It is easily swaged for base-plates, if the precaution be taken to anneal it almost at a white heat for a few seconds. Annealing at an ordinary dull red has no effect, and the swaging is apt to cause it to tear, especially in deep palates, ridges, etc. The alloy draws readily into wire, and makes a useful form of strengthener for lower dentures where rigidity is required. The wire is much increased in strength if hammered, and its colour and freedom from oxidation is not objectionable if it should show in the finished dentures. It may be soldered with 20 or 18 carat gold solder, but does not flux so readily as gold. In casting it shows marked contraction, and the formation of a heavy coating of oxides on the surface for cast plates tends to blunt the casts, and even impedes the metal flowing through the gates. The high temperature required to melt it is also against its use for this purpose. (See Casting under Pressure.)

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* Huntingdon and Macmillan.

Preparation of Aluminium Bronze. — This alloy is known under several trade names, such as Victoria metal, etc., each make differing slightly in composition. Dr. Percy was the first to make it. Sir W. Roberts-Austin gives its tensile strength at 100,000 to 120,000 pounds per square inch in sheet form, and in castings from 70,000 to 80,000 pounds per square inch. The copper is first melted, and then the aluminium added, using an ordinary well-tempered crucible. The union of the metals is accompanied by a rapid rise in temperature, the mass being raised to a white heat. The molten alloy should be granulated by being run into water and remelted several times, to insure perfect homogeneity; otherwise the metal is liable to be very brittle. In some commercial forms lead is present, and the proportion of copper is subject to considerable variation, the variation in the aluminium deciding the figures per cent. of the alloy; *e.g.*, 95 copper, 5 aluminium, is a 5 per cent. alloy.

Copper or Sullivan Amalgam.—This is the only form in which copper is employed alone alloyed with mercury. The resulting amalgam has been long famous for its great edge strength, lack of contraction, and in its own place forms a most useful amalgam for restoring tooth substance lost through caries. It should always be confined to the posterior teeth, as it darkens through oxidation, the black stain usually permeating the dentinal tubules, unless the cavity walls have been sealed with a layer of oxyphosphate of zinc or other cement. It it readily inserted, and should be condensed with pluggers or burnishers to insure solidity, adaptation to the cavity walls, and to remove excess of mercury. The amalgam takes from four to five hours to harden, but even then it is unsafe, where large restorations have been made, to bring the force of mastication to bear upon it, as it is liable to alter in shape or fracture. Patients should be cautioned against the use of the filled tooth that day. (See Dental Amalgams.)

Making of Copper Amalgam. — Chemically pure copper sulphate (bluestone) is dissolved in warm water to form a weak solution. The weaker the solution, the finer the grain of the finished amalgam. Sheet zinc or iron is suspended in the solution, when the copper is deposited. The clear water is poured off and the copper transferred to an earthenware mortar ; dilute sulphuric acid is added, and the copper stirred vigorously with the pestle ; fresh water and acid are added, and the copper washed until the addition of acid does not discolour the solution. It is then well washed with water to free it from acid, and the mercury added in the proportions of 2 of mercury to 1 of copper by weight. A little nitrate of mercury may be added to assist in the amalgamation. The mercury and copper are rubbed together until the mercury is evenly distributed, a little dilute sulphuric acid added again, the amalgam washed in hot water, dried, and the surplus mercury expressed

4 gall.

½ gall

Add Sug

to clean

through chamois leather. The amalgam is then pressed into small button-shaped moulds, and allowed to harden. The amalgam on being heated becomes quite plastic, and may be resoftened without injury to its properties, provided that the heat is not sufficient to volatilize the mercury. It is sufficient if it is heated in an old iron spoon until mercury beads appear on the surface.

2 Properties [illegible]

CHAPTER X

METALLURGY OF GOLD

Symbol, Au.	Atomic weight, 196·60.
Specific gravity, 19·30.	Melting-point, 1,064° C.

OCCURRENCE.—Gold is found almost exclusively in the native condition, chiefly in quartz, veins, and as nuggets in alluvial deposits, these deposits being formed by the disintegration of auriferous rocks. It is seldom found pure, being almost invariably alloyed or combined with traces of silver; it also occurs in the ores of silver, copper pyrites, iron pyrites, and many of the lead ores. It is found, too, combined with the rarer metals tellurium, platinum, and palladium, the traces of these metals generally being small. Combined with tellurium, gold occurs in varying quantities; thus,

Calaverite, $AuTe_2$, contains 40 per cent. gold.

Sylvanite, or graphic tellurium, $(AuAg)Te_2$, contains 24 per cent gold.

Nagyagite, or black tellurium, $(PbAu)(TeS)_2$, contains 5 to 9 per cent. gold.

White tellurium, $(AuAgPb).(TeSb)_3$, and Petzite, $Ag_2Te_2Au_2Te$, also contain sufficient gold to repay treatment.

PREPARATION OF GOLD.—The treatment of ores for the extraction of gold is determined by the form in which the metal occurs, and other metals combined with it. The processes may be classified as under:

1. Extraction of gold by simple washing, or by dressing gold-bearing sand, gravel, etc.

2. Extraction of gold by dry process—*i.e.*, by concentrating the gold in the ore in a gold and lead alloy, or gold, silver, and lead alloy, and recovering the gold by cupellation.

3. Extraction of gold by wet process—*i.e.*, by extracting the gold from aqueous solutions.

4. Extraction of gold by combination of wet and dry processes, such as—

(*a*) By obtaining the gold as an alloy of gold and mercury (amalgamation).

(*b*) By obtaining the gold as an alloy of gold and silver, or gold, silver, and copper, and dissolving the silver and copper.

5. Extraction of gold by electrolysis—*i.e.*, by obtaining the gold as a gold-silver or gold-silver-copper alloy, and parting these metals from the gold by means of electrolysis.

1. **Extraction of Gold by Simple Washing.**—This process is only applicable to gold-bearing soils and alluvial deposits. The pan and cradle treatment of the early miner has disappeared. The modern sluice consists of a series of boxes or troughs 16 to 21 inches wide, and 9 to 12 inches deep. Each box is about 12 feet in length, the series extending several hundred yards in many mines. Water is allowed to flow through the sluice, which is inclined so as to keep up a steady flow. The gold-bearing soil is shovelled in at the head of the sluice, and, being caught in the water, is carried along. The earthy matter is broken up, and sets of short transverse wooden ridges catch the pebbles, and help to break up pieces of clay, etc. The gold, as it becomes free of the earthy matter, sinks, and is collected in a series of pockets let into the bed of the sluice; there it is caught in mercury, from which it is after-

wards freed by heat. The pan and cradle process formerly employed entailed a loss as great as 50 per cent. at times; with the modern sluice the loss is very trifling.

Amalgamation Process.—When the ore is present in quartz form, and the gold present in paying quantities, and provided the ore is one of the variety known as "free-milling" ores, or is one that will yield its gold readily to mercury, the quartz is crushed to powder in the mills or stamps, as described under the MacArthur-Forrest Process. The powdered quartz is mixed with water, and allowed to flow slowly over copper plates heavily coated with mercury. Those plates are ridged in places to obstruct the even flow, and are caused to vibrate to bring the finely divided gold down into contact with the mercury. The mercury absorbs the gold from the water, and the gold is recovered by distilling the mercury, which is recovered by condensing the vapours; the gold is then melted to ingots. The residue, or "tailings," from this process is generally treated by the cyanide process. There are many modifications of this process.

2. **Extraction of Gold by Dry Processes**—(1) *By concentrating the Gold in Lead.*—The ore is melted in a reverberatory furnace, and lead, either as galena, litharge, or lead slag, or any refuse containing lead, is charged into the furnace with gold-bearing ore. The lead acts in much the same way as mercury; that is, it collects any gold and silver present by reason of its affinity for them, and the gold and silver are afterwards separated by cupellation.

(2) *By using Iron and Lime.*—This process is employed for poor ores. The ores are roasted in air, and mixed with lime, when any metallic sulphides present are converted into oxides. The charge is melted in a blast-furnace, when the quartz of the ore and the lime combine to form a slag, beneath which the gold, with any silver and iron sulphide present, collects. These metals are

treated by one of the "parting" processes to be described.

3. **Extraction of Gold by Wet Processes**—(1) *The MacArthur-Forrest or Cyanide Process.*—This process depends upon the solvent action of potassium cyanide on gold, and is especially adapted to such ores as yield their gold readily to mercury, such as free-milling ores, and to the tailings from the amalgamation process. When quartz is under treatment, the first step is to reduce the stone to powder by some form of crushing machine. The crushing is seldom carried beyond the point when the powder will pass through a mesh of thirty to the linear inch, as if it is finer than this the gold is apt to be carried off in the scum or to remain in suspension. Where the quartz has been previously treated by the amalgamation process, however, it may be crushed as fine as sixty to the inch, the modern tube mill being employed. This powder in South African mines is soaked, or "leached," in potassium cyanide solution for three or four days for fine ores, and up to fourteen for coarse ores, the quantity of potassium cyanide used being from 0·35 to 0·6 pound per ton of ground ore or tailings. The ore is passed through several tanks containing the solution, until all the gold has been dissolved; the solution is then transferred to a series of long troughs, averaging about 24 feet long, 3 feet wide, and from 2 to 2½ feet deep. These troughs are subdivided, each compartment containing freshly cut zinc covered with wire mesh, with four holes to the inch. The action may be expressed theoretically thus,

$$2KAuCy_2 + Zn = KZnCy_4 + Au_2,$$

although more zinc has to be used in practice. The gold is deposited as a black slime, the zinc is dissolved with suitable acids, and the gold melted and run into ingots.

Electrolytic Deposition from the Auro-Cyanide Solution—(2) *Siemens and Halske Process.*—Electricity has been employed with success to displace zinc for the above purpose. Lead cathodes are used, and iron anodes; the gold is deposited on the lead cathodes, which are cupelled for the recovery of the gold. The current is low, being around 7 volts. There are several modifications of the above processes, such as the substitution of potassium bromide for the cyanide, but the descriptions give the principles governing the processes in general.

4. **Extracting Gold by Combination of Dry and Wet Processes**—*Chlorination Process*.—In this process advantage is taken of the readiness with which gold combines with chlorine to form auric chloride. The ore treated by this process contains the gold in close intimacy with other metals, such as pyrites ore. The ore is roasted in a reverberatory furnace to drive off as much volatile matter as possible, and to render it more porous. It is then withdrawn, moistened, placed in tubs, and exposed to the action of chlorine gas. The gold and iron present are converted to chlorides, which, being soluble, are washed out with water, and the gold deposited by sulphuretted hydrogen being passed through the solution. Ferrous sulphate is said to give even better results than the gas for the deposition of the gold, the gold coming down in a purer condition.

The processes included under group No. 5 will be found detailed under the smelting process given, in the parting or refining process to be given, and in the Siemens and Halske electrolytic process.

Treatment of Tellurium Gold Ores.—The ores are boiled with strong sulphuric acid, dissolving the tellurium and any lead, zinc, copper, and part of the silver, present, and leaving the gold and silica as a residue. The gold is then treated by cupellation. The tellurium solution is evaporated to a syrup, soaked in weak hydrochloric acid, and any gold or silver present is deposited and removed. The tellurium is deposited with liquid sulphur dioxide in the elemental state.

Parting or Refining of Gold.—The gold as produced by the processes given is seldom, if ever, pure; and the series of processes necessary to obtain the gold in the pure state, and to separate it from such valuable metals as platinum, silver, etc., is referred to as the parting or refining of gold. The treatment which the gold receives is governed by the metals present. The processes may be divided into three classes :

1. Dry methods, in which litharge, sulphur, sulphide of antimony, chlorine, or certain cement powders consisting of brick-dust, are the agents.

2. Wet methods, where nitric or sulphuric acids are used to effect the separation.

3. The electrolytic method depends upon the fact that, when solutions containing gold and silver are electrolyzed, the gold remains at the anode, while the silver passes to the cathode, the electrolyte being an acidulated solution of silver nitrate.

Dry Method of Parting Gold—Miller's Process.—The gold is enclosed in fireclay crucibles provided with well-fitting covers. It is covered with borax and lids luted to their places. The crucibles with the gold are placed within a second, and sometimes a third, crucible, with a layer of borax between each to prevent the gold passing into the body of the crucibles. The crucibles may also be treated by dipping into a solution of borax, drying, and heating to a high temperature before use. This renders them impervious to the precious metals or their chlorides. Each is provided with a luted cover, and into the cover of the crucible containing the gold is led a clay pipe, to convey chlorine gas as soon as the gold has melted. The gold absorbs the chlorine first as quickly as it enters ; the metals present are converted into their respective chlorides, while volatile metals are given off as the temperature is increased. The vapours given off are at first white, and, when the process is complete, of an orange colour. The gold collects at the bottom of the crucible commercially pure, while the silver is present as the chloride. Miller fused the chloride with a little potassium carbonate. This reduces a small quantity of the silver, which, again, in separating from the rest of the chloride carries with it any gold present. The silver, either as the chloride or metallic silver, may be dissolved in sulphuric acid, the gold removed, and the silver deposited from the solution by iron plates, etc.

Cementation Process.—The powder used consists of 1 part common salt to 2 parts brick-dust. The gold is laid in layers in crucibles made of porous clay, each layer being separated by some of the cement powder. The crucible and its contents are heated over wooden fires for twenty-four to thirty-six hours, and kept at a bright red heat. A large quantity of water is given off by the wood during combustion, which, entering the crucible, brings the salt, silica, and water, into combination at a red heat. The sodium of the salt is taken up by the oxygen from the water, and combines with the silica, forming sodium silicate. The chlorine of the salt takes up the hydrogen of the water to form hydrochloric acid. This acid, attacking the silver, forms silver chloride, which passes into the sides of the crucible. This process, repeated several times, yields a commercially pure gold.

Parting of Gold by using Sulphide of Antimony.—The process depends upon the fact that, if an alloy containing silver and gold be melted with sulphide of antimony, the silver combines with the sulphur, and the gold with the antimony. The alloy must contain at least 50 per cent. of gold, and the process must be repeated several times to insure complete parting. The antimony is driven off by heat, and the silver separated by being melted with lead or iron. Any silver still present in the gold is removed by nitric acid.*

Nitric and Sulphuric Acid Process.—The use of these acids is based upon the power which they have of converting silver and copper into their nitrates and sulphates, if employed as hot concentrated solutions.

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* Schnabel and Louis, vol. i.

and upon the fact that they have no action upon gold. The metal to be treated is either in fine granules or thin sheets, and the hot acid added until all chemical action ceases—a sign that the silver and copper present are dissolved. The liquid is decanted, and the gold as the residue is melted and cast into ingots.

Electrolytic Process.—If a highly diluted solution of silver nitrate be electrolyzed between anodes of gold and cathodes of silver, the silver adheres to the anode. By enveloping the anode in a fine cotton bag, the gold may be collected in the latter. The gold can be freed from any silver by digesting with strong nitric acid, the gold so treated being 999 fine.

Preparation of Chemically Pure Gold.—The gold obtained by the ordinary parting processes just described averages from about 996 to 999 parts pure in the 1,000. As it is essential that the gold used for filling purposes be as pure as possible, that obtained by the above processes is generally best adapted to the purpose. The gold is dissolved in nitro-hydrochloric acid (aqua regia, a mixture of 1 part nitric to 2 parts of hydrochloric acid). To this solution of gold chloride are added potassium chloride and alcohol, which deposit any platinum present. The platinum is recovered, and the solution then diluted until there is 1 gallon of water for every ½ ounce of gold solution. Any silver present will combine with the potassium chloride, and be deposited as silver chloride.

This process generally occupies a few days, as the silver, by reason of its strong affinity for gold, separates out very slowly. Oxalic acid, ferrous sulphate, stannous chloride, or a stream of sulphuretted hydrogen, is added to the solution, and the gold deposited.

The character of the deposited gold is very much influenced by the reagent used, and by the strength of the solution. Oxalic acid deposits the gold as a spongelike mass if used in diluted solution, and as crystals or leafy foil if used in strong solution. Ferrous sulphate deposits gold more granular than otherwise, the gold having a brown colour. Gum-arabic or sugar, if added to diluted gold solution and heated, deposits the gold as shreds, oxalic acid being formed by the decomposing of the gum-arabic or sugar. The electrolytic deposition of gold has already been described. Oxalic acid seems to be most favoured of the reagents in the use for preparing dental golds.

PROPERTIES OF GOLD.—As seen in the mass gold is the only yellow metal. When freshly precipitated, the colour, as has been said, varies with the reagent used. Gold when pure is almost as soft as lead, and can be welded in the cold state. Annealing tends to toughen the metal, but increases its ductility and tenacity, and renders it more malleable and cohesive. The term "cohesive" as applied to gold is somewhat analogous to that of "weldability" as applied to iron and other metals. If two pieces of gold-foil be annealed and brought together with a light flip or pressure, it will be found impossible to separate them. Under the glass or microscope it is seen that this cohesion is very intimate. Advantage is taken of this property in building up contours on fillings, the cohesion enabling the operator to build on gold to the metal already in place after the restoration has been carried beyond the walls of the cavity. Pure gold inserted thoroughly into a cavity should not scale on the surface when exposed to the force of mastication, nor disclose any tendency to friability, change of shape, or discoloration.

Gold is more malleable and ductile than silver, leaves of gold having been rolled to $\frac{1}{282,000}$ inch, silver only to $\frac{1}{10,000}$ inch. Taken at $\frac{1}{282,000}$ inch, 56 square inches of this foil only weigh 1 grain (Greenwood). As an example of its ductility, 1 grain of gold has been drawn into wire form to 500 feet (Percy).

Pure gold is greatly affected by the presence of impurities, even small traces of lead, antimony, platinum, iridium, or arsenic, having a most powerful effect on the malleability, ductility, tenacity, and cohesiveness. As a conductor of heat and electricity, gold ranks next to silver. This property of conductivity is one which demands attention when the metal is being inserted within reasonable distance of living pulp tissue. Frequently the cavity is lined, and the pulp protected by a lining of non-conducting oxyphosphate or oxysulphate of zinc cement. Pure gold either at ordinary temperatures or strongly heated is not affected by the atmosphere. Sulphuretted hydrogen does not affect the metal at ordinary temperatures, but double sulphides of gold and alkali metals are formed by fusing gold with an alkaline sulphide. Chlorine readily attacks the metal forming the chloride. Gold is dissolved by any reagent which liberates chlorine, which accounts for the solvent action of aqua regia. Oxalic acid precipitates gold from solution ; so also arsenious acid, stannous and antimony chloride, arseniuretted and antimoniuretted hydrogen, sulphur, sulphur dioxide, and the ferrous salts. Gold is not acted upon by nitric, hydrochloric, sulphuric, or any single acid, except the selenic.

GOLD FOR FILLING PURPOSES.—The gold employed for filling purposes is nearly always pure, seldom being lower than 999·5 fine. It is employed in several forms—as cubes or cylinders, made from very thin foil rolled into coils, and cut to the different sizes ; as foils of various thicknesses, the number of the foil generally denoting the number of grains in the sheet. For general work, the number of thickness ranges from 30 grains to 60 grains per sheet. Cubes, cylinders, and foils, are prepared under two classes—the cohesive and non-cohesive. The advocates of non-cohesive gold claim for its use greater softness in working, insuring a more accurate adaptation to the cavity walls, and greater hardness to the completed filling. Its use is usually confined to simple cavities—that is, cavities with all four walls standing. The non-cohesion of the separate pieces is against its use in compound cavities, especially where much contouring is necessary. It is not perfectly understood how non-cohesive golds are prepared, as all forms of pure gold without special treatment are cohesive after annealing. Gold, however, may be rendered non-cohesive by the following :

1. By alloying with copper, platinum, or silver, in small quantities.
2. By immersion in a metallic salt solution, such as ferrous sulphate.
3. By the deposition of finely divided carbon on the surface.
4. By special mechanical treatment during the rolling and beating.
5. By forcing the gold to occlude certain gases.

Many of the so-called "non-cohesive" golds, as foil and cylinders, are only non-cohesive until they are annealed, when they lose this property ; others, again, remain non-cohesive after repeated annealings. Moisture, grease, dust, and even humidity of the atmosphere, all tend to reduce cohesiveness in gold. The annealing process should be carried out carefully. The practice of exposing the gold to the naked flame of the commercial quality of methylated spirits reduces the cohesiveness, prevents equality of annealing, and causes scaling, friability, etc. The sheets of mica supplied for the purpose work efficiently, as do many of the electric annealers. The lamp with absolute alcohol flame is advocated by some operators for annealing heavy foils. Unless where the alloy of gold and platinum is used, the annealing should not be carried beyond a cherry-red heat. The alloy, however, behaves best with a bright-red heat, and should be kept at this temperature for a few seconds. Matt golds, or gold deposited as crystals, shreds, and leafy deposits, are generally of the cohesive type. They may be had as cubes, blocks, or strips, and are deposited from a solution of pure gold by means of various reagents. Thus—

1. Ferrous sulphate deposits gold as a light brown-coloured powder.

2. Oxalic acid deposits gold, according to the strength of the solution, from a spongy deposit to a brown powder.

3. Electricity is now employed, the cathode being platinum, and the anode being a plate of pure gold. The deposit is in the crystalline form, as supplied in matts. The other reagents are seldom employed for depositing gold as matt for dental purposes.

Matt gold is frequently employed for basing large cavities, as it is readily inserted, resembling amalgam in many of its working properties. By some operators it is carried to the surface of the cavity ; others, again, prefer to finish the filling with foil or cylinders, as these, they consider, give a denser surface, and are less liable to change of shape. The gold supplied in the various forms alloyed with platinum, while giving a much tougher surface, is discarded by many on account of its colour. As foil, it appears very light in colour, but when highly polished looks almost black. In matt form, when inserted, it resembles a low-carat gold, being very red in hue. Many of these alloys contain, besides gold and platinum, traces of silver and copper. Annealing renders them cohesive, but they never reach the kid-like softness of most of the pure golds. In foil form they are admirably suited for making matrices for fused porcelain inlays, etc., the alloy being tougher, more elastic, and bearing more burnishing without thinning or tearing. If annealed frequently, it can be made to spring from the cavity without change of shape. The melting-point is also higher than that of pure gold.

ALLOYS OF GOLD.

Pure gold is too soft and too expensive for most industrial and dental purposes. When chemically pure, it is known by jewellers as "fine" gold, and described as 1,000 fine, or of 24 carat fineness. The term "carat" is difficult to trace, some ascribing it to the Greek word *keration*, a seed or bean formerly used as a weight. Now it is regarded as simply expressing a unit, whether an ounce, pound, or pennyweight, each unit being divisible into twenty-four parts. Each part of an alloy or other metal present will reduce the carat fineness. Thus, if there be 22 parts gold, 1 of silver, and 1 of copper, we have the 24 carats reduced by 2, yielding 22 carat gold, the figure of the carat always expressing the parts of pure gold present. Gold of 22 carats is known as "standard gold," a term used by goldsmiths, and when it is said that a gold is so many carats better or worse than "standard gold," it means higher or lower than 22 carat gold. Alloying of gold generally has in view the cheapening of the production, the hardening of the metal, and the lowering of the fusing-point. Silver and copper are the two metals mostly employed for this purpose, the silver overcoming to a great extent the reddening effect of copper.

Gold Plate.—In the laboratory pure gold is only employed in cases of continuous gum work and for bridge work. In such cases the foundations or bases are of platinum or iridio-platinum, the pure gold being employed as a solder when high fusing bodies and enamels are employed, because the pure metal will not discolour the porcelain or delicate gum tints by oxidation during firing.

Crown Gold.—Plate for crowns is usually of 22 carat gold, which is tougher and harder than the pure metal, does not discolour in the mouth, and, being easily bent, is readily and accurately adjusted. British gold coin is highly suitable for the purpose, the colour being very good. Professor C. L. Goddard gives the following as having the colour of pure gold and of 21·6 carat:

No. 1.		No. 2.	
Pure gold ..	90 parts.	Coin gold ..	50 parts.
,, silver ..	5 ,,	Pure ,, ..	45 ,,
,, copper ..	5 ,,	,, silver ..	5 ,,

Crown gold is generally of No. 4 English gauge, the solder being 20 carat, or No. 00, for the seam of the ferrule, and No. 1 and chips of 18 carat gold for loading the top where the crown is made in two pieces. When seamless crowns are made, the top is loaded with No. 1 gold solder. Many prefer to make the ferrule with British coin gold or from one of the above formulæ, and the top from such as the following, the platinum imparting greater hardness:

Pure gold	22 dwts.
,, silver	18 grs.
,, copper	1 dwt.
Platinum	6 grs.

Gold Plate for Bases.—The gold for these seldom exceeds 18 or 20 carat, the most common being 18 carat for general purposes, and of 7 or 8 English gauge thickness. In the mouth these carats do not readily discolour, are easily kept clean, and do not irritate even the most sensitive mucous membrane. Silver and copper are the two metals used to reduce the carat.

Alloys of Gold used in Dentistry as Bases, Clasps, and Wires.

20 CARAT GOLD FOR BASE-PLATES.*

Pure gold ..	20 dwts.	American coin gold	20 dwts.
,, silver ..	2 ,,	Pure silver ..	20 grs.
,, copper ..	2 ,,	,, copper ..	18 ,,

18 CARAT GOLD FOR BASE-PLATES.* Ordi

Pure gold ..	18 dwts.	Pure gold ..	18 dwts.
,, silver ..	2 ,,	,, silver ..	3 ,,
,, copper ..	4 ,,	,, copper ..	3 ,,

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* Richardson's "Mechanical Dentistry."

16 CARAT GOLD FOR BASE-PLATES.*

Pure gold	16 dwts.	Pure gold	11 dwts.
,, copper	4 ,,	,, silver	3 dwts. 6 grs.
,, silver	4 ,,	,, copper	2 dwts. 6 grs

20 CARAT PLATINIZED GOLD FOR CLASPS AND WIRES.†

Pure gold	20 dwts.	Coin gold	20 dwts.
,, copper	2 ,,	Pure copper	8 grs.
,, silver	1 dwt.	,, silver	10 ,,
,, platinum	1 ,,	Platinum	10 ,,

18 CARAT PLATINIZED GOLD FOR CLASPS AND WIRES.†

Pure gold	18 dwts.	Pure gold	18 dwts.
,, silver	4 ,,	,, copper	3 ,,
,, copper	1 dwt.	,, silver	2 ,,
Platinum	1 ,,	,, platinum	1 dwt.

PLATINIZED GOLD FOR CLASPS AND WIRES.†

17 Carat.		*16 Carat.*	
Pure gold	17 dwts.	Pure gold	24 dwts.
,, copper	4 ,,	,, copper	2 ,,
,, silver	2 ,,	,, silver	1 dwt.
,, platinum	1 dwt.	,, platinum	1 ,,

It is a general practice, when using platinized gold for making flat plate, to displace half the copper with platinum, and for clasps, where the hardening effect of the copper is necessary, to displace half the silver with platinum.

Gold Solders.—Solders generally range from 20 carat down to 12 carat, although many are found much lower. Below 12 carat they oxidize rapidly, and the purpose is to solder with as high a grade as the base, clasp, etc., will permit. The solder must always be lower in carat and fusing-point. Professor Goddard gives a simple method of producing a solder suitable. Take 5 parts of the gold plate itself, and add 1 part brass or silver solder. This produces a solder which flows freely. Zinc added to many gold solders has the effect of lowering the fusing-point, and causing the solder to flow better on becoming liquid.

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* Richardson's "Mechanical Dentistry."

† Essig and Koenig.

Dorrance's alloy for reducing gold to solder gives good results :

Copper	6 parts.
Silver	2 ,,
Zinc	4 ,,

22 Carat Solder.

Pure gold	22 grs.
Brass	2 ,,

20 Carat Solder, or No. 00.

Pure gold	20 grs.	Pure gold	5 dwts.
Zinc	1½ ,,	,, silver	12 grs.
Silver solder	3 ,,	,, copper	6 ,,

20 Carat Solder.

Pure gold	20 dwts.
Dorrance's alloy	4 ,,

18 Carat Solder, or No. 1.

Coin gold	30 parts.	Coin gold	19½ dwts.
Pure silver	4 ,,	Pure silver	2½ ,,
,, copper	1 part.	,, copper	1 dwt.
Brass	1 ,,	Brass	1 ,,

16 Carat Solder, or No. 2.

Pure gold	11 dwts.	Pure gold	11 dwts. 12 grs.
,, silver	3 dwts. 6 grs.	,, silver	3 dwts.
,, copper	2 dwts. 6 grs.	,, copper	1 dwt. 12 grs
		,, zinc	12 grs.

15 Carat Solder (Jeweller's "Best Quality").

Pure gold	15 dwts.	Standard gold*	16½ dwts.
,, copper	5 ,,	Pure copper	3½ ,,
,, silver	4 ,,	,, silver	4 ,,

15 Carat Ordinary.

Pure gold	15 dwts.	Standard gold	17 dwts.
,, copper	4 ,,	Pure copper	4 ,,
,, silver	4 ,,	,, silver	2 ,,
Brass	1 dwt.	Brass	1 dwt.

* 22 carat.

14 CARAT SOLDER.

Pure gold	14 dwts.
,, silver	5 ,,
,, copper	3 dwts. 12 grs.
,, zinc	1 dwt. 12 grs.

12 CARAT, OR NO. 3.

Pure gold	12 dwts.	Standard gold	13 dwts.
,, copper	6 ,,	Pure silver	6 ,,
,, silver	5 ,,	,, copper	5 ,,
Brass	1 dwt.		

MELTING-POINTS OF VARIOUS CARATS OF GOLD (C. ASH AND SONS).

	F.°
Fine or pure gold	1,980
22 carat	1,800
20 carat	1,760
18 carat	1,700
17 carat platinized band gold	1,800
16 carat band gold	1,640
16 carat	1,620

MELTING-POINTS OF VARIOUS CARAT GOLD SOLDERS (C. ASH AND SONS).

	F.°	C.°
22 carat, for use with fine gold	1,730	943
20 carat, for use with 22 carat gold	1,650	899
18 carat, for use with 20 and 18 carat gold	1,560	849
No. 00, for use with crown gold	1,620	882
No. 1, for use with 16 and over 16 carat gold	1,530	832
No. 2, for use with over 13 carat gold	1,480	804
No. 3, for general work and for dental alloy	1,430	777

Calculations of Carat Fineness of Gold Alloys.

1. *To find the carat of an alloy.*

RULE 1.—Multiply the weight of the gold present by the given carat, and divide by the combined weights of the metal of which the alloy is composed.

Example 1.—Gold, 6 parts of 24 carats; silver, 2 parts; copper, 1 part. Total, 9 parts. Find the carat of the alloy.

$6 \times 24 = 144 \div 9 = 16$ carats.—*Answer.*

Example 2.—Gold, 24 parts of 22 carats ; copper, 8 ; silver, 6. Total, 38 parts. Find the carat of the alloy.

$24 \times 22 = 528 \div 38 = 13{\cdot}9$ carats.—*Answer.*

Rule 2.—As the weight of the alloyed mass is to the weight of gold it contains, so is the carat of the latter to the carat of the former.

Example.—18 dwts. pure gold, 2 dwts. silver, 4 dwts. copper. Total, 24 parts. Find the carat of the alloy.

Parts.		Gold present.		Carat given.		
24	:	18	: :	24	=	18 carat.

2. *To reduce the gold to a required carat.*

Rule 1.—Multiply the weight of the gold taken by its carat, and divide by the carat required. The quotient gives the weight of alloy to be made. Subtract from this the weight of gold used, and the difference is the weight of inferior metals to be added.

Example.—Reduce 4 ounces of 20 carat gold to 16 carats.

$4 \times 20 = 80 \div 16 = 5$. $5 - 4$ (the total weight of the alloy) $= 1$ ounce alloy required.

Rule 2.—As the required carat is to the carat used, so is the weight of the mass used to the weight of the alloyed mass when reduced. The weight of the mass used subtracted from this gives the quantity of alloy required to effect the reduction.

Example.—Reduce 4 dwts. of 18 carat gold to 12 carat.

$12 : 18 :: 4 = 6 - 4 = 2$ dwts. alloy required.

3. *To raise the gold to a higher carat.*

Rule 1.—Multiply the weight of alloy used by the difference between its carat and that of the metal added, and divide by the difference between the carat of the metal to be added and that of the alloy required. Subtract the weight of the metal used, and the answer gives the amount of the gold required.

Example 1.—Raise 10 pennyweights of 16 carat gold to 18 carat, using pure gold.

Multiply 10 by 8 (difference between 16 and 24), and divide by 6 (the difference between 18 and 24).

10 × 8 = 80 ÷ 6 = $13\frac{1}{3}$ − 10 (the weight of the metal used). *Answer :* $3\frac{1}{3}$ dwts. of pure gold required.

Example 2.—Raise 11 dwts. of 18 carat gold to 20 carat, using 22 carat gold.

11 × 4 ÷ 22 − 11 = 11 dwts. of 22 carat gold required.

RULE 2.—As the alloy in the required carat is to the alloy in the given carat, so is the weight of the alloyed gold used to the weight of the changed alloy required. Subtract the weight of the alloy used; answer gives the amount of gold required.

Example.—Raise 4 dwts. of 16 carat gold to 18 carat by adding 22 carat.

First subtract 16 from 22 = 6, then 18 from 22 = 4.

4 : 6 : : 4 = 6 dwts. minus 4 = 2 dwts. of 22 carat gold required.

Gold and Platinum.—Platinum added to gold imparts hardness and elasticity, but produces a paler colour. When over 5 per cent. is added, the alloy is much harder, more liable to fracture on swaging, and oxidizes more rapidly. In excess of a " content " the alloy is acted upon by nitric acid. In foil form for filling purposes the amount of platinum seldom exceeds 2 per cent. In plate for clasps, wires, etc., from 1 to 5 per cent. added imparts greater strength and elasticity, an important property for clasps. The alloy is seldom used for base-plates, being too hard and elastic unless the platinum is kept very low in percentage The two metals alloy readily, copper being employed as the medium to effect the alloying.

Gold and Silver.—Silver added to gold impairs the colour, increases the hardness without reducing malleability, and reduces the melting-point considerably. It is for these properties, hardness and reduction of the melting-point, that silver is employed. The metals alloy readily, although silver is seldom added to gold alone.

Gold and Copper.—Copper and gold unite freely, the copper diffusing itself through the gold very perfectly. The union of the metals is accompanied by a slight rise of temperature, some writers holding that when 76 parts of pure gold and 24 parts of pure copper are melted together a chemical combination ensues. Such an alloy is crystalline and brittle, and is never employed. Copper reddens the colour of gold, reduces the melting-point, increases hardness and toughness, but reduces the malleability and ductility.

Gold and Palladium.—Palladium added to gold, even in small quantities, renders the metal brittle and unworkable. The alloy is seldom prepared, and the two metals can be separated only with great difficulty. Iridium has a similar effect.

Gold and Iron.—Essig mentions an alloy known as "blue gold," containing 75 per cent. iron and 25 per cent. gold. Many of the old bronzes contained traces of gold in their composition, the gold lending a beauty to the colour, besides lessening oxidation. The effects of such metals as tin and zinc, when present in gold alloys, are best studied under amalgams, as they are never added singly.

Lead present in gold, even to the extent of 1 part in 1,000, renders the gold brittle. Antimony and bismuth have a similar effect if added.

TREATMENT OF SCRAP GOLD.—The presence of impurities exerts a powerful influence on the working properties of gold. Such metals as arsenic, antimony, lead, zinc, and iron, if present in small quantities, lessen malleability, ductility, and tenacity, and if present to any appreciable extent make the gold brittle, friable, and unworkable. Dental gold is specially liable to become contaminated with such metals as platinum from porcelain teeth, etc., and with iridium as the iridio-platinum alloy ; with traces of zinc from dies, lead from counter-dies, steel from broken fret-saws, dust from metal files, and traces of dental alloy. The greater portion of these may be readily removed by simply picking them from the gold before melting, but there frequently remain traces which can be eliminated only by special treatment. The removal of such metals as platinum and iridium requires special care, as it is always attended with great difficulty, and often with loss of precious metals. Steel filings and broken saw-blades are readily removed by passing a good magnet into and over the scrap gold. The crucible used should be well tempered, well coated inside with borax, and raised to a red heat, so that the borax will glaze and prevent any of the gold passing into the body of the porous crucible. Ordinary scrap gold requires no further treatment than being brought to the melting-point, having plenty of borax added, being kept at a bright red heat for a few moments, and then poured into an ingot and rolled in the usual way.

Messrs. Fletcher of Warrington supply several useful appliances for the melting of gold and other metals, economy of heat being the governing principle. Their melting tray and ingot combined is especially useful where gold up to a few ounces is being treated. The gold can be poured from the crucible, free from molten borax, on to the fire-clay tray, and when it becomes thoroughly liquid the apparatus is tilted, and the gold run into the clean and well-oiled steel ingot mould. If, after rolling, the gold is found to be brittle, even when well annealed, it should be further dealt with as brittle gold.

TREATMENT OF BRITTLE GOLD.—The gold is brought to the melting-point, and potassium nitrate added. The crucible should be placed in a strong upward chimney draught, when this reagent will help to oxidize such metals as lead, iron, steel, copper, silver, tin, zinc, and antimony. This process may be repeated several times; the gold is poured into a fresh, clean, and tempered crucible coated with borax and sal ammoniac (ammonium chloride), with powdered charcoal added. The chlorine combines with most of the base metals present to form volatile chlorides, which either pass off or are caught in the borax slag Mercuric chloride has been employed for this purpose, but the poisonous nature of its fumes render its use in ordinary dental laboratories inadvisable.

Where platinum is present in sufficient quantities to cause brittleness, the gold has to be subjected to one of the " parting " processes already described.

Iridium is more difficult to remove. The gold is alloyed with three times its weight of silver; the iridium, by reason of its higher specific gravity, sinks, when most of the gold and silver may be poured off. The process may be repeated several times with what remains in the crucible; then the alloy is digested in sulphuric acid when the silver is dissolved, and the iridium is recovered as a deposit.

TREATMENT OF LEMEL AND SWEEP.—The sweepings from the dental operating-room and laboratory contain a large proportion of organic material. To extract the gold, bring the sweep to a dull red heat, which burns off most of the organic matter, and reduces it to ashes. These are mixed with the following: For every 50 parts of ashes by weight, 5 parts sodium carbonate, 5 parts borax, 2 parts potassium bisulphate or nitre, and 5 parts common salt. The lemel is mixed with the sodium carbonate, borax, and nitre, covered with common salt, and raised to melting-point in a large crucible, and when all action of the flux has ceased the metal is poured into an ingot. The further treatment must be regulated by the behaviour of the gold when rolled. If brittle, the process already described is followed. In smelting works, where large quantities are treated, the ashes are charged into a reverberatory furnace, and lead added to concentrate any gold and silver. If silver is present in quantity, some iron is added to combine with any sulphur contained in the slag, and thus prevent the carrying off of the silver. The metals are separated by cupellation.

ASSAYING OF GOLD.—The assay process is divided into two divisions—the wet process of parting already dealt with, and the fire assay.

Fire Assaying.—This process is based upon the readiness with which gold and silver will combine with lead, and the power possessed by lead to decompose metallic salts. Silver chloride, for instance, if melted in presence of lead, will yield

$$2AgCl + Pb = 2Ag + PbCl_2,$$

which equation describes what has taken place. If volatile compounds, such as antimony, arsenic, mercury, etc., are present, the metal is subjected to a preliminary roasting at a temperature sufficiently high to volatilize or oxidize these. With the precious metals, the quantities of the metals assayed in each firing are divided into what are known as "assay tons," and generally marked "a.t." Each a.t. weighs 29·166 grammes, and as many of these "tons" may be treated as desired. With each charge the reducing agents must also be present in definite quantities; thus, for each a.t. of metals present there must be also 1 a.t. of litharge (lead oxide), 2 a.t. of soda ash, ½ a.t. of borax glass, and 3·5 grammes of crude potassium bitartrate (argols). Each charge is placed in a well-tempered crucible of ample dimensions. As the temperature rises the disturbance ceases, Andrew A Dewar.

and when the metals have melted the charge is allowed to cool slowly. It is then withdrawn from the crucible, and the slag broken from the metal, which is in the form of a lead button. This process is best adapted for assaying gold ores, whereas with silver ores the scorification process is of the greatest value.

Scorification Process.—In this process advantage is taken of the fact that, if silver be melted with lead in a current of air, the lead reduces and oxidizes any insoluble metallic salts present. " Test lead " or " lead shot " is used in place of litharge, 10 a.t. of test lead being added for each a.t. of silver ore present. The scorification dish or crucible is shallow, and of a finer texture than the ordinary fire-clay crucible. One-half of the lead is placed in the scorifier, then the silver, and the remainder of the lead added as a covering. The charge is kept molten for some time, borax being added from time to time, and the volatile compounds and reduced oxides are carried off in the current of air, generally established as an upward draught. These are generally seen rising as a thick, greasy vapour, and when this ceases, and the lead is seen clear and watery, the charge is poured off, and the slag broken free of the metal, which is next cupelled.

Cupellation Process.—The dish or cupel used in this process is round and thick, with a shallow concavity to receive the assay charge. The cupel is composed of bone-dust moistened with water and pressed into shape, care being taken not to produce a dish too dense, as this would retard the absorption of the oxidized lead. This process also depends upon the oxidizing effect of lead oxide upon the metals present, and on the fact that the lead oxide fuses, and is absorbed by the bone-ash of the cupel, carrying with it any base metals present, or is partly dispelled by oxidation.

The lead button being placed in the hollow of the cupel, the latter is placed in a modified form of muffle furnace, and the door closed. The heat is gradually increased until the charge is melted, care being taken to maintain the temperature as evenly as possible: cooling means loss of metal through some of it passing into the body of the cupel; and overheating, loss of metal by oxidation. As the process proceeds, it is noticed that the same thick vapour hovers over the charge, and that the bulk of metal is gradually lessening, a film of oxides appearing on the surface, and then quickly disappearing. When the last of the lead has disappeared into the cupel, the rest of the metal suddenly turns on its axis, and becomes covered by the most varied and beautiful tints, this change being referred to as "the brightening of the assay." The heat is now increased to expel any traces of lead present, and the cupel allowed to cool slowly. The metal remaining should contain the precious metals present, minus the other metals that were present as impurities. There is always a slight loss of silver, partly through oxidation, and partly through the lead carrying some of it off. The process takes from twenty to thirty minutes to complete, when the metals, such as gold, platinum, or silver, may be recovered by one ot the parting processes already described. It has been found that there is not complete separation of the gold and silver present unless the quantity of silver is at least thrice that of gold; so that, where doubt exists on this point, silver may be added even to excess. The process described refers generally to the assaying of alloys containing gold, silver, platinum, zinc, mercury, etc., such as are met with in dental amalgams; but where silver or gold alone is being assayed, the process is slightly modified. With large quantities of metals such as are treated at lead-works, where the lead contains paying quantities of silver, the process is modified by the substitution of larger vessels in the cupelling. In the German cupellation process, for example, cupels are large enough to receive charges of 25 tons of metals. Such processes are best studied from text-books on lead, silver, and gold.

Check Assaying.—Where an accurate assay is required, careful weights are taken during the assaying, and a "check" assay taken. In this check assay, a quantity of pure gold or silver, approximately equal to that present in the assay, is taken. It is mixed with the same quantities of the metals present in the original alloy, as disclosed by the parting process, in order to bring it through the scorification, cupellation, and parting. The exact weight of gold and silver is taken, and any increase is due to the presence of silver. This increase is deducted from the weight of gold in the original assay, and so greater accuracy is reached.

Assaying by Touchstone.—In assaying articles of jewellery, use is frequently made of what goldsmiths refer to as the "touchstone," a dark, smooth, and very hard stone of basaltic origin, or even of black slate, over which the article is drawn so as to leave a line of minute particles of the metal. The streak is then touched with nitric acid, with a trace of hydrochloric acid and water added, when such metals as copper and silver are dissolved. The streak is then compared for colour with a set of "touch needles" (a series of gold alloys of definite compositions), and from this comparison the carat of the article is found. Rose states that the assay by the touchstone or touch needles is best adapted for alloys below 18 carats, and that the gold present in an alloy can be determined correctly to 5 parts per 1,000.

COLOURING OF GOLD.—This term refers to the process by which a film of pure gold is obtained on articles made from gold below the carat of fine gold, and which is generally employed to improve the colour of the gold. The gold is heated over a Bunsen to a dull red heat, and plunged into nitric or sulphuric acid while hot. The acid dissolves out most of the silver and copper from the surface, leaving a layer of comparatively pure gold.

There is also a dry process, in which the gold is immersed in a paste composed of common salt, alum, and saltpetre. The action is similar. It is not usual to colour gold below 12 or 13 carats, as the lower the carat the greater the action of the acid, which, dissolving the silver and copper, leaves the surface irregular.

ELECTRO-GILDING.—The solution or bath is of chloride of gold and potassium cyanide, the positive pole of pure gold, and the negative the article to be gilded suspended on a copper wire. The article to be gilded is made perfectly clean by immersion in a hot solution of caustic potash, and rubbed with a clean metal scratch-brush. The gilding bath is kept at between 160° and 212° F.; the larger the article, the higher the temperature required. The bath remains fairly constant owing to the gradual solution of the gold plate of the positive pole. The varieties of gilding apparatus used by the profession vary, the batteries developing a current of from 2 to 3 volts. When sufficient gold has been deposited, the article is withdrawn, washed, and polished.

GOLD-BEATING.—The pure gold is cast into ingots, $\frac{3}{4}$ inch in width, each weighing from 1 ounce to 2 ounces. The hammer employed is about 16 pounds, with a circular and slightly convex face, 4 inches in diameter. The ingot is annealed and hammered on a steel anvil until it is $\frac{1}{8}$ inch in thickness, when it is rolled out in ribbon form to $\frac{1}{3000}$ inch. The metal is frequently annealed during the process to prevent fracture or tearing. The ribbon is now cut into 1-inch squares, and placed in piles of 150, with a layer of specially toughened paper or vellum dividing the layers. The pile is rolled into two wrappings of this paper or vellum, placed on a marble block or anvil, and hammered. The 1-inch squares are hammered until they are 4 inches, which are again cut to 1-inch squares and piled as before, with a layer of "gold-beaters'-skin" between them. This "skin" is a membrane prepared from the peritoneal or serous coat of the intestines of the ox. These piles or "shoders" are again hammered until the required thinness is attained. Pure gold can be reduced much further than its alloys, and may be made to present a surface 650,000 times as large as it originally possessed.* For dental foils, the gold of 1,000 fine is reduced as detailed, the number of the foil denoting the number of grains in a 4-inch-square sheet; thus, No. 30 foil has 30 grains per 4-inch sheet, and so on.

PURPLE OF CASSIUS.—This compound of gold, so called from its discoverer, Andreas Cassius, was first detailed in 1685, and largely employed at that time for imparting a beautiful ruby-red colour to glass for art purposes. It is used by dental porcelain manufacturers for imparting the gum tints to porcelains used in manufacturing gum-sections teeth and in continuous gum work. The exact composition of the compound is extremely uncertain. It is known to contain the oxide of tin and metallic gold, but the distribution of these in the compound is difficult to express. Bloxham gives it thus:

$$Au_2O.SnO_2 + SnO.SnO_2.4H_2O.$$

There are numerous ways of preparing the compound:

1. By adding a mixture of stannous and stannic chlorides to a solution of auric chloride, made as neutral as possible.

2. By adding stannous chloride to a solution of ferric chloride until the yellow colour changes to a pale green; then add to a solution of auric chloride, when the gold is precipitated.

3. By melting together 2½ parts gold with 3½ parts tin and 15 parts silver, the metal being fused under borax to prevent oxidation. The alloy is treated with nitric acid to dissolve out the silver, leaving the precipitate of a deep purple colour (Greenwood).

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* Huntingdon and Macmillan.

4. By melting together 240 grains pure silver, 24 grains pure gold, and 17½ grains pure tin (Professor Wildman). The metals are melted, and the silver is dissolved out as described in No. 3, by adding nitric acid to the alloy, when a strong chemical action is set up.

The acid reduces the alloy to a fine state of division, and is added until all action ceases. The acid is now poured off, the filtrate washed repeatedly with water, and the tests for silver made by adding common salt. If no white precipitate forms, the powder is washed in absolute alcohol and bottled.

Purple of Cassius shows great variations in colour even when made from the same formula. Its colour can frequently be improved by treating it with nitric acid immediately before using.

Dark

FULMINATING GOLD.—A buff-coloured precipitate which explodes with violence when dry if struck or gently warmed. Exact composition unknown. Turner says it is usually prepared by addition of ammonia to trichloride of gold, with the probable formula :

$$Au_2O_3.4H_3N.H_2O.$$

Newth gives it as a compound formed between auric oxide and ammonia.

CHAPTER XI

PLATINUM

Symbol, Pt.	Atomic weight, 194·30.
Specific gravity, 21·50.	Melting-point, 1,775° C.

OCCURRENCE.—Platinum occurs principally in the metallic state, and frequently in the same alluvial deposits as gold, as nuggets and flattened grains of various sizes. It is most frequently found associated with the metals iridium, palladium, osmium, rhodium, and ruthenium, these metals with platinum composing the "platinum group" or "platinum metals." Native platinum contains from 60 to 80 per cent. of platinum, the remainder being some of the other metals of the group, with traces of gold, copper, and iron. The metal also occurs combined with silver, gold, copper, and iron, also in the mineral sperrylite ($PtAs_2$), which contains 50 per cent. platinum and 40 per cent. arsenic. Native platinum is used as a source of the metal. The chief impurities found in the native metal are quartz, spinel, corundum, titanic, chrome, and magnetic iron ores, gold, osmo-iridium, serpentine, and zircon.

PREPARATION OF PLATINUM.—In the extraction of platinum the ore is concentrated by washing, and any gold in the free state removed by mercury, which amalgamates with this metal, leaving the platinum free. The processes may be divided into two—the wet and dry methods.

Wet Methods—(1) The Wollaston Extraction Process.—This process depends upon dissolving the other metals present with the platinum, and leaving the platinum as a deposit, or bringing the platinum to solution, and leaving such metals as osmium and iridium as the deposit. The platinum ore is digested with nitric acid, which dissolves out the copper, silver, iron, or lead, present. The residue is washed to free it of any nitrates, and then digested with hydrochloric acid, and heated to dissolve out any magnetic iron present. Again it is washed, more hydrochloric acid added, and heated, and small quantities of nitric acid added from time to time. Platinum chloride is formed, leaving iridium, palladium, and osmium, as a residue. The platinum chloride solution is mixed with ammonium chloride, which deposits the platinum as ammonia chloride of platinum. The double chloride is heated in plumbago crucibles to drive off the ammonia, and the platinum is left as a grey spongy mass, known as "spongy platinum," which is annealed to redness and rolled, hammered, or pressed into sheet, etc., or fused by the oxyhydrogen flame, and run into ingots. This process is best adapted for extracting platinum in which the gold is present in very small traces; it fails, however, to remove the iridium and rhodium present.

(2) **Schneider's Process.**—To remove iridium and rhodium. The solution of platinum, after the palladium, osmium, and part of the iridium, have been removed, is evaporated almost to dryness; it is then diluted with water, soda added until the solution is alkaline, and the mixture boiled with alcohol. The precipitate from this is dissolved in hydrochloric acid, and ammonium chloride added, when the platinum is deposited as the pure double chloride.* The iridium and rhodium are converted to the sesquichlorides, which are not precipitated by the addition of ammonium

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* Schnabel and Louis, vol. ii., p. 783: "Schneider's Process."

chloride. The wet method is principally used for the extraction of platinum.

Dry Methods—Deville and Debray Process.—In this dry process the intention is to concentrate the gold, platinum, iridium, osmium, etc., in lead, and cupel the alloy thus formed, afterwards separating the metals by one of the parting processes, as given under Gold. When a platinum ore is treated, the iridium, osmium, and palladium, if present, fall to the bottom of the lead, and by concentrating these, by removing the more liquid lead from time to time, these metals are removed and recovered separately as granules. The lead containing the platinum is cupelled, when the metal is recovered as the spongy platinum, which is either rolled, hammered, pressed, or melted, as already described under the Wollaston Process. Another method, a combined wet and dry process, is to alloy the platinum with 6 parts lead, and granulate the alloy by pouring it into water. It is then digested in dilute nitric acid to dissolve any copper, iron, palladium, and part of the rhodium. The filtrate is digested in aqua regia, which dissolves the platinum, lead, iridium, and osmium. The lead is then deposited by sulphuric acid, and the platinum by adding chloride of ammonia and sodium. The chloride of platinum thus formed is melted with potassium and ammonia bisulphate, and any rhodium present washed out with water. The platinum is recovered as the spongy platinum.

The Deville Furnace.—This furnace, for use with the oxyhydrogen flame, is made of two blocks of calcined lime hollowed in the centre, and clamped together with iron bands. The nozzle of the blowpipe is platinum-tipped, and let into the furnace from above, the aperture also being lined with platinum. Coal gas is conveyed through one tube, the oxygen passing through another and meeting the coal gas at the point of ignition. The products of the combustion pass through a tap-hold let into one end of the lime block, and through which also the melted platinum is poured. A fresh furnace is required for each melting.

ELECTRO-DEPOSITION OF PLATINUM.—The electrolyte is an acid solution of gold chloride with excess of hydrochloric acid. The anodes are sheets of gold, alloyed with the metals of platinum group, silver, copper, etc.; the cathodes are of pure gold-foil. The tensions are low, and the gold from the anode only is deposited; the platinum, being alloyed with the gold, passes into solution, enriching the electrolyte, but is not deposited. The other metals are not dissolved, but collect at the anode as a slime. This process is not much in favour, as the other processes are quite efficient.

PROPERTIES OF PLATINUM.—In colour platinum is a dull grey unless when rolled, when it is bright and of a white colour. When pure it is very malleable, ductile, and very tenacious. It does not oxidize at ordinary temperatures. The solvents for the metal are aqua regia and potassium cyanide in concentrated solutions. Nitric, sulphuric, and hydrochloric acids have no action upon the metal. In the mouth platinum is not affected by oral secretions, a property of great value in the making of pins for artificial teeth, especially for vulcanite work, where, through the contraction of all forms of vulcanite, the pins, if made of base metals, are liable to oxidize. Its high melting-point, 1,775° C. (1,770° C.*), is especially valuable in bridge work, continuous gum work, and as a matrix metal where high fusing porcelains are used for inlays. It is employed for wiring electric furnaces, and for trays for firing inlays, continuous gum work, etc. For root canal fillers, needles and points of hypodermic syringes, the property of the metal in withstanding the action of iodine, sulphuric acid, etc., is valuable, where these and other remedies act as corrosive to steel. Platinum possesses the property of occluding gases to a certain extent, and also the remarkable property of inducing chemical combination between oxygen and hydrogen, the combination of these being accompanied by heat. Both these properties are most marked in the variety known as "platinum black," a preparation capable of occluding 800 times its volume of oxygen. It is prepared by warming platinum chloride in caustic potash dissolved in alcohol. Like silver, the metal absorbs oxygen when molten, giving it up again when cooling, and "spitting" as in the case of silver. It ranks amongst the heaviest of the metals, as is seen from its specific gravity. The metal is extremely ductile, and Essig instances the wire drawn by Wollaston: by plating with silver and passing through a draw-plate and then dissolving, the silver produced a wire $\frac{1}{30000}$ inch in diameter, 1 grain of which would, if extended, stretch one mile. Platinum is seldom found pure in commerce, as the following analyses show:*

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* "Mineral Industry," 1892, p. 384.

(1) Platinum, 99·9; rhodium, 0·01; arsenic, 0·01.
(2) Platinum, 99·9; iron, 0·0001.
(3) Platinum, 99·29; iridium, 0·32; ruthenium, 0·04; iron, 0·06; copper, 0·07.

Impurities exert a powerful effect upon the properties of the metal, reducing the ductility, malleability, tenacity, and generally lowering it in value for dental purposes, except where special effects are sought. Minute traces of iron and arsenic render the metal friable and brittle—an effect of much importance in the composition of pins for porcelain teeth. For the effects of other metals, see Alloys of Platinum.

ALLOYS OF PLATINUM.

Platinum and Gold.—The alloy in sheet form is used for bands and base-plates, as foil and matts for filling purposes, the platinum increasing the strength and elasticity of gold generally. The metals alloy readily, the alloy possessing a lower fusing-point than platinum. Platinized gold for clasps and base-plates may contain: Pure gold, 20 dwts.; copper, 2 dwts.; platinum, 1 dwt. (See Gold.) An alloy of 9·5 of gold to 1 of platinum possesses the same density as platinum, and is infusible in ordinary furnaces. As platinum is increased in these alloys, the tendency is for nitric acid to attack them. In foil form the alloy of gold and platinum is supplied in several shades of colour for filling purposes. It can be obtained so light as almost to resemble a freshly-inserted silver-tin amalgam. The alloy is harder to work than pure gold, possesses greater edge strength in the finished filling, but the colour, especially when given a high polish, is almost black seen in certain lights. In matt form it is generally too red in colour when finished, and, unless the annealing receives very careful attention, the tendency is for the alloy to scale. In foil form the alloy is of service for matrices for fused inlays, the higher melting-point and greater elasticity being valuable properties for this purpose.

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* *Comptes Rendus*, cxlviii. 1177-1179, May 3, 1909.

Platinum Solder.—Gold 75 parts, platinum 25 parts, yields a solder suitable for using with platinum as a base, or where iridio-platinum is used as sheet, bar, or wire. It is chiefly of use in soldering attachments where high fusing porcelains are used, as in continuous gum work.

Platinum and Iridium.—Iridium added to platinum increases its hardness, elasticity, and raises the fusing-point. For continuous gum work the alloy iridio-platinum contains 10 to 15 per cent. iridium, giving an alloy of great strength, infusible with the ordinary blow-pipe, and mostly used as a strengthening bar for lower dentures, crown posts, etc. The alloy is also used in the making of standard weights, and in traces in certain makes of pins for artificial teeth. Excess of iridium tends to brittleness, while 78·7 parts platinum to 21·3 parts iridium withstands the action of aqua regia.

Platinum and Silver.—The metals alloy well, platinum even in small quantities increasing the hardness, and lessening the oxidation, of silver in the mouth.

Dental alloy contains from 3 to 10 grains of platinum per pennyweight of silver. Platinum in excess of 10 per cent. (the "content") added to silver causes the alloy to be attacked by nitric acid. Dental alloy may be soldered with 16 and 18 carat gold solders. (See Silver.)

MELTING-POINTS OF DENTAL ALLOY (C. ASH AND SONS).

No. 1 Dental Alloy	2,150° F.
No. 2 Dental Alloy	1,750° to 1,800° F.

Platinum and Copper.—The metals alloy readily, the resulting alloy resembling gold in colour. Copper lowers the fusing-point of the metal, and is generally added in small quantities to the alloys of gold and platinum. The alloy tarnishes rapidly in the mouth and in air.

Platinum and Mercury.—Platinum and mercury do not alloy well, the platinum requiring an excess of mercury to render the alloy plastic. In dental amalgams, platinum has been displaced to a large extent on account of this property, its place having been taken by zinc. (See Amalgams.) Platinum alloyed with tin, lead, and zinc, yields alloys brittle and friable, and of little practical utility.

IRIDIUM

Symbol, Ir.	Atomic weight, 192·50.
Specific gravity, 22·42.	Melting-point, 2,500° C.

OCCURRENCE.—Iridium occurs chiefly associated with platinum, and in the alloys iridosmine and osmo-iridium associated with osmium. It also occurs in several golds, especially in gold obtained from California and British Columbia.

PREPARATION.—The alloy of iridium and osmium is generally found as very fine granules, is intensely hard, and insoluble in aqua regia. To extract the iridium, the alloy is fused with five times its weight of zinc, the zinc volatilized, and the alloy osmoiridium crushed and sifted. The sifted alloy is mixed with barium peroxide, kept at a white heat for an hour, and boiled in aqua regia. The osmium is thus converted into osmium peroxide (OsO_4), which, when heated to 100° C., passes off as a pungent and poisonous vapour. The iridium remaining in solution is separated as the insoluble double chloride by the addition of potassium chloride, the barium having been removed previously by adding sulphuric acid. The iridium is recovered from the double chloride.

PROPERTIES.—Iridium is a steel-white metal possessing great strength, brittle when cold, but moderately malleable if raised to a red heat. It is seldom used separately, the alloy iridio-platinum being its usual form in use. (See Platinum.)

The alloy osmoiridium as the fine granules, found native, is largely made use of for pointing fountain-pens, being hard, insoluble in aqua regia, not oxidizing in the presence of moisture or air. A compound of iridium with 7 per cent. phosphorus is also largely used for this purpose.* Iridium generally contains traces of platinum and ruthenium, is not acted upon by the acids when pure, but if oxidized at a red heat in hydrogen is dissolved in aqua regia. Apart from the alloys already given, the metal has no general application.

PALLADIUM

Symbol, Pd.	Atomic weight, 106·30.
Specific gravity, 11·50.	Melting-point, 1,500° C.

OCCURRENCE.—Palladium is found in the ores of platinum in quantities seldom exceeding 1 per cent. It also occurs occasionally in the native state, comparatively pure, associated with platinum.

PREPARATION.—The metal is obtained chiefly by the parting process from the solution of the crude double chloride of platinum, after the platinum has been precipitated. Sodium carbonate and a solution of cyanide of mercury is added. Palladium cyanide is formed, which, when heated, and the mercury driven off, yields metallic palladium.

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* Huntingdon and Macmillan, p. 524.

PROPERTIES.—Palladium is the most easily fused of the platinum group, the melting-point being almost equal to that of wrought iron. It is readily dissolved in hot nitric acid. In colour the metal is white, with a slight tinge of yellow, resembling an alloy of platinum and gold with excess of platinum. The metal is malleable, fairly ductile, harder than platinum, and is oxidized slightly if heated to redness in air. The solvent for palladium is aqua regia. It is attacked by iodine, and may thus be distinguished from platinum, on which iodine has no effect. As a constituent of dental amalgams, the metal at present has fallen into disuse. Its scarcity, cost, and the fact that the amalgams formed showed excessive expansion, led to its abandonment. The addition of mercury is accompanied by heat, even when palladium is alloyed with other metals. The amalgams also discolour to a great extent, the blackening tending to permeate the tooth structure. The metal occludes 643 times its volume of hydrogen if heated to redness, the absorption of the gas being accompanied by an elevation of temperature.

ALLOYS OF PALLADIUM.—The metal alloys readily with most other metals, but its comparative scarcity and cost prohibit its general use.

Palladium Alloy.—An alloy of silver and palladium possessing almost similar properties and uses as dental alloy. Is malleable, ductile, and can be readily swaged in sheet form. Possesses a lower atomic weight than dental alloy, 1 ounce in sheet of similar thickness covering a surface 25 per cent. greater than the platinum alloy.* The metals alloy well, and disclose little tendency to separate on heating.

C. Ash's Circular, August, 1910.

CHAPTER XII

MERCURY

Symbol, Hg.	Atomic weight, 199·80.
Specific gravity, 13·59.	Melting-point, − 39° C.

OCCURRENCE.—Cinnabar, the red sulphide of mercury (HgS), is the chief source of the metal, and is often mixed with the free metal. Mercury also occurs native in small quantities, as a protochloride or native calomel, as the iodide and chloride in native amalgams of silver and gold, and also in several fahlores.

PREPARATION.—Mercury is generally prepared by dry methods of distillation, the wet methods and the electrolytic never having found much favour commercially. The dry methods may be divided into two groups :

1. Those in which the mercury is extracted by heating the cinnabar in air.
2. Those in which the mercury is extracted by heating cinnabar with lime or iron, the air being excluded.

Of these, the first is most largely, if not almost exclusively, employed.

By heating Cinnabar in Air.—This process consists in heating cinnabar in a shaft or reverberatory furnace with an excess of air to a temperature sufficiently high to cause the oxygen of the air to combine with the sulphur in the cinnabar to form sulphur dioxide, the mercury separating out in metallic form. The following formula explains the action :

$$HgS + O_2 = SO_2 + Hg.$$

The Iridian Process.—In this process the furnace consists of a shaft crossed by several perforated arches, on which the crude ore is placed—the largest pieces on the lowest arch, the smaller pieces on the higher, and the unreduced ore from previous furnace charges, as a powder, on the top arch. This powder is mixed with water and clay, and shaped into blocks. When the fire is kindled on the floor of the shaft, the heated products of combustion rise, the air combining with sulphur dioxide, at the same time liberating traces of sulphuric acid. As the heat increases the mercury distils over, and condenses as it comes in contact with the air of the condensing chambers, placed to right and left of the central shaft. Most of the mercury is collected from the condensers nearest the furnace, the others containing some mercury mixed with heavy dust. In some instances inclined plains are inserted in the last chamber of the series, over which water is caused to flow, so keeping the air as cool as possible, and preventing uncondensed mercury from escaping.

Reduction with Iron, Lime, etc.—There are several of these processes, the essential features of which consist in charging the cinnabar, mixed with iron or lime. into closed vessels. The mercury distils, and is drawn through pipes let into the base of the vessels, which are either immersed in water or kept cool by water circulating round them. The use of lime is said to yield better results. The action may be expressed thus :

$$4HgS + 4CaO = 3CaS + CaSO_4 + 4Hg.$$

Purification of Mercury.—The mercury as produced by these processes generally contains traces of the metals contained in the ores, such volatile metals as zinc, antimony, and bismuth, having passed over with the mercury ; while tin and antimony, being soluble in mercury, are dissolved as they pass over with it. In the various methods of extracting the mercury by the dry processes, no special precautions are taken to prevent the volatilizing and solution of these metals, as it would be difficult to keep the furnace at a heat sufficient to distil the mercury alone. As some of these metals are worth recovering, however, the temperature is raised with the purpose of volatilizing them, and they are recovered from the liquid mercury. The following methods are employed :

1. Impurities not soluble in mercury are removed by passing the mercury through chamois leather, when they are left adhering to the skin.
2. Redistilling at a low temperature, when the mercury alone passes over.
3. Lead, bismuth, and zinc, are removed by washing the mercury in dilute nitric acid. The metals are converted to nitrates, together with a small proportion of the mercury.
4. Pronitrate of mercury may be used instead of nitric acid, the base metals displacing the mercury in the pronitrate, which, thus liberated, combines with the mercury on being purified.
5. **Electrically Pure Mercury.**—In these processes commercial mercury is the anode, and carbon rods the cathodes. The bath or electrolyte contains 17 per cent. nitric acid and 4 per cent. potassium nitrate. The current is never permitted to rise above 0·75 volt, and the metals, such as zinc, cadmium, bismuth, lead, tin, etc., pass into solution, leaving the mercury pure.*

PROPERTIES OF MERCURY.—Pure mercury always presents a bright clear surface, and if poured slowly from a shallow vessel or over a flat surface runs with a clear and sharply-defined edge. The presence of ordinary commercial impurities may be detected by the dull surface of the mercury ; by the appearance of fine dust or grit on the surface if the mercury is shaken; and by the formation of a long-drawn-out ending or tail if it be poured or made to run slowly over a level surface, such as a hand-mirror. For dental purposes, such as the amalgamating of the alloys for fillings, electrically pure mercury is used, since the presence of such base metals as are either present as impurities or added as adulterations would injure the composition and properties of the amalgams.

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* Smith's "Dental Metallurgy," p. 128.

Mercury possesses the singular property of being liquid at ordinary temperatures, and having a melting-point of −39° C. Below this temperature the metal becomes solid, contracting considerably on solidifying. In the solid state the specific gravity is increased by almost 6·50, owing to the contraction of the metal, and the consequent drawing of the molecules closer together. When solid, the metal is white, ductile, malleable, and crystalline. It boils at 360° C., forming a colourless vapour. When heated to about 270° C., it combines with oxygen to form mercuric oxide. The oxide is again decomposed into oxygen ~~or~~ metallic mercury. Mercury readily combines with gold, silver, platinum, bismuth, tin, zinc, and cadmium; with copper and iron less readily, unless the metals are previously brought to a fine state of division.

Combined with another metal, mercury forms an amalgam, and, as gold and silver are readily soluble in mercury, advantage is taken of this property in the extraction of these metals. (See Gold and Silver.)

Mercury and Tin.—The action of mercury on other metals is readily seen if an ingot of tin be immersed in mercury. In less than one minute the ingot will be rendered friable, and if allowed to remain longer will be completely dissolved.

Mercury and Silver.—Silver combines readily with mercury, and when they are combined in certain proportions the union of the metals is accompanied by the evolution of heat.

Mercury and Gold.—Gold and mercury will readily combine, but the amalgam is friable and never used. Both gold and silver as cylinders are employed to remove excess mercury from the surface of amalgam fillings. Care should always be taken to prevent mercury from coming in contact with gold fillings, crowns, plates, etc., as the mercury penetrates the gold, and in the case of fillings causes the surface to discolour, flake, and, if absorbed in excess, to break up. Crowns are badly discoloured by mercury, and, where the mercury is in excess, are acted upon rapidly by attrition during mastication.

Mercury and Copper.—The amalgam formed by the alloying of these metals, known as "copper" or "Sullivan" amalgam, is the only instance in which mercury is alloyed with another single metal for dental purposes. (See Copper.)

Mercury and Platinum.—Mercury combines less rapidly with platinum than with gold, and the metals are never employed together as an amalgam.

Mercury and Palladium.—The metals combine readily, the amalgam showing expansion when set. In the mouth the amalgam becomes almost jet black, the darkness being transmitted to the tooth structure. The amalgam is never employed as a filling material. (See Palladium.)

Mercury and Bismuth, Cadmium, Antimony, or Lead.—Mercury combines with these more or less readily. It is added also as a constituent of some fusible metals to lower the melting-points.

Mercury and Nickel.—The metals combine when the nickel is finely divided. Nickel has been used as a constituent of low-grade amalgams, but nickel and mercury as an amalgam has no practical application.

Mercury is used for Dental Purposes—

1. Added to alloys to form amalgams for filling purposes.
2. Added to fusible alloys to lower the melting-points.

3. As the compound vermilion as a colouring agent for rubbers.

4. As mercuric chloride ($HgCl_2$), also known as "corrosive sublimate," it is used as a germicide, in solutions of 1 in 2,000 and 1 in 3,000, in general cavity toilet, washing out roots, and for sterilizing purposes. Care must be exercised in its use, however, as the compound attacks silver and nickel-plating, and gradually steel itself. Platinum nerve canal fillers, nozzles of syringes, etc., are usually employed in applying it about the mouth. The compound is extremely poisonous. Mercurous chloride (Hg_2Cl_2), also known as "calomel," mercurous and mercuric iodide, are best studied under Materia Medica.

SILVERING OF MIRRORS.—In the process known as the "silvering of mirrors," an amalgam of tin and mercury is employed. The glass to be silvered is made perfectly free of scratches, and cleaned with putty powder. Tin-foil is spread on a flat surface, rubbed free of creases, and covered over with a thin film of mercury. The glass is laid on, and pressure applied to bring its surface into perfect contact with the amalgam and to express air. The pressure is maintained for twenty-four hours. The table on which the glass is laid is tilted gradually at intervals to allow the excess of mercury to be run off, until the glass is in the upright position. The silvering is allowed several days to harden, and then covered with a lead paint to protect it.

VERMILION.—This compound is a crystalline variety of cinnabar, the native sulphide of mercury, and is well known by its characteristic bright colour, the colour generally being brightest when the compound is pure. There are two main processes for manufacturing vermilion.

Chinese Method.—This consists in heating 4 parts of mercury with 1 part of sulphur in an earthenware vessel, which is covered with an iron plate luted on to exclude the air, and the lid kept damp during the prcoess. The heat is kept up for twenty-four hours, the earthenware vessel broken up, the sublimate of the purest colour selected as the highest grade, and on being washed is ready for use.*

Dutch Method.—This consists in heating 7 parts of mercury with 1 part of sulphur, keeping the compound at fusing-point for several hours, and then pouring it on iron hot plates. After being kept fused for several hours, it is allowed to cool. On being broken up and washed, the vermilion is ready for use.

Various wet methods may be employed.

1. Precipitate mercury from a salt, using sulphuretted hydrogen, and heat the black sulphide so obtained until it is sublimed. This, on being washed with an alkaline solution of potassium sulphide, yields vermilion of a good colour.

2. Triturate 100 parts mercury with 38 parts sulphur, and digest in a solution containing 25 parts caustic potash and 150 parts water. The mixture is kept as near 45° C. as possible for several hours, water being added to replace that lost by evaporation, when vermilion of a good colour is obtained.†

Properties of Vermilion.—Vermilion when pure contains 86 per cent. of mercury, is very finely divided, and of a bright scarlet colour. The Chinese variety is considered the best for colour and purity. The compound is soluble in aqua regia and sodium sulphide, but insoluble in dilute nitric, concentrated sulphuric, or hydrochloric acid, cyanide of potassium, sulphide of ammonia, or alcohol. It is used largely as a pigment, and for dental purposes for colouring vulcanizing rubbers. It has been frequently blamed for inducing sensitive conditions of the palate when present in base-plate rubbers, especially in those of low grades. Many of such rubbers, when seen under the magnifying-glass, disclose great porosity of the surface, which, on absorbing dirt, may induce irritation. In several rubbers where vermilion is said not to be used as a colouring agent, however, there is generally less complaint on this score. Vermilion in commerce is frequently adulterated with free mercury, red lead, arsenious sulphide, etc., all of which are capable of causing irritation even if present in small traces.

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* Greenwood.

† Turner's "Posthetic Dentistry."

CORROSIVE SUBLIMATE.—This compound occurs native, and may also be prepared by decomposing mercuric sulphide. This is done by heating it with small quantities of salt, the temperature being gradually increased, when the mercuric chloride sublimes, and condenses on the sides and cool parts of the heating apparatus. A trace of magnesium dioxide is generally added to prevent the forming of mercurous chloride. It may also be prepared by heating mercury in an excess of chlorine gas, or by dissolving mercuric oxide in hydrochloric acid.

CHAPTER XIII

ZINC

Symbol, Zn. Atomic weight, 65·30.
Specific gravity, 7·15. Melting-point, 418° C.

OCCURRENCE.—

Name.	Composition.	Percentage of Zinc in Pure Mineral.
Zinc sulphide, or blende	Zinc and sulphur	67
Zinc oxide, zincite, or red zinc	Zinc and oxygen	80
Zinc carbonate, or calamine	Zinc, oxygen, and CO_2	52

Also electric calamine, so called because its crystals become polar when heated; Willemite, an anhydrous silicate; Franklinite and Gahnite.

The sulphide, known as "zinc-blende," from the German word *blenden*, to dazzle, is also known as "black jack," and is the chief source of the metal. It is seldom pure, being generally associated with the sulphides of iron, copper, lead, manganese, and less frequently with silver and cadmium. The ore usually contains from 40 to 60 per cent. zinc. The carbonate is the next in importance, and is the most abundant ore of zinc. It also contains iron, manganese, etc. The other ores, with the exception of the oxide, are less abundant, contain less zinc, and are seldom employed for the extraction of the metals.

PREPARATION OF ZINC.—There are two classes of processes—the dry and wet. Zinc belongs to that class known as "volatile metals," passing into the gaseous state if heated beyond its fusing-point, from which state it is recovered by a process of condensation. The ores to be treated should be rich in zinc, and as uniform in composition as possible, care at this stage simplifying the after-treatment very considerably. Before heating, the ores are carefully picked and washed clean of useless matter, and are subjected to a preliminary calcining at a low temperature. This, in order to drive off as much of the impure matter as possible, converts sulphides into oxides, and breaks up the ore held in its matrix of quartz, etc. The calcining also facilitates the distilling of the metal, and volatile impurities, such as arsenides, etc., which would exert a powerful effect on the properties of the finished metal, are driven off. The calcined ore is mixed with carbon, placed in closed fireclay vessels or in crucibles supplied or connected with some type of condenser to effect the cooling of the zinc vapour. It is then heated to 926·5° C.,* 930° C.,† 940° C.,‡ the boiling-point of zinc, and the temperature gradually increased to 1,300° C. to insure the complete removal of the zinc. The various processes may be classed as—

1. Distillation in horizontal retorts, as in the Belgian method.
2. Distillation in muffles, as in the Silesian method.
3. Distillation in the Belgo-Silesian furnaces.

The English and Carinthian processes are no longer used.§

Belgian Method.—The calcined ore is placed in fireclay cylinders arranged in tiers, all sloping downwards, with as many as eighty cylinders in a tier. The zinc, as it escapes, is led through iron piping to the condenser, where it is collected.

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* Greenwood. † Newth. ‡ Essig.

§ Schnabel and Louis, vol. ii., p. 131.

The Silesian Method.—The calcined ores are placed in muffles instead of cylinders, as in the Belgian method, it being held that the muffle can withstand a higher temperature than the cylinder without change of shape or fracture, and consequently admits of a more perfect extraction of the zinc. The condensers are generally long iron tubes, into which the vapour passes.

The Belgo-Silesian Method.—This process differs from the processes already detailed only in the arrangement of the muffles and the type of condensing tubes, which have a cup or depression in the base through which the zinc may be tapped. In all these processes some type of reverberatory furnace fired by solid coal or gas is employed for heating the vessels containing the zinc ores.

The Wet and Electro-Metallurgical Methods.—As zinc cannot be separated from its solutions by any metal not oxidized at ordinary temperatures, the wet methods only admit of the production of compounds of zinc, from which the metal may be extracted by heat. The wet methods are employed only in conjunction with the dry methods. These combined methods have been tried on poor ores, but have been discarded. The electrolytic extraction of zinc is from a solution from which the zinc is separated by means of an electric current. The process is chiefly made use of in the removal of zinc from an alloy, when the alloy may be used as the anodes.

REFINING OF ZINC.—The metal as produced by the dry methods is generally contaminated with traces of such metals as lead, frequently in excess of 5 per cent., and iron about 0·1 to 0·2 per cent. For commercial purposes the lead is removed, as its effect would be to reduce the extensibility of the metal. The zinc is brought to the melting-point very slowly, and after being kept molten for some time it is allowed to cool slowly. The impurities, such as iron, rise to the surface, and are ladled off, or the zinc is ladled off, leaving the lead present.

For dental purposes, such as for cement fillings, and as a constituent of amalgams and solders, the pure metal is produced by bringing the zinc to solution, precipitating it with a suitable reagent, and melting the zinc under carbon.

PROPERTIES OF ZINC.—The metal has a bluish-white colour, and possesses less metallic lustre than most other metals. Freshly cast zinc, if broken, shows a fracture of a tabular structure, which quickly tarnishes in contact with air. Apart from loss of brilliancy, the air, if dry, has no action upon it, but moist air causes a film of oxide to form, which protects the metal from further oxidation. When heated to redness, it quickly oxidizes, and burns with a bluish flame, giving off a white flocculent powder, the oxide somewhat resembling wool, and at one time known as "philosopher's wool." Carbonic acid acts upon the metal, forming a coating of the carbonate. Hot water tends to oxidize zinc, but cold water, unless it contains CO_2 in solution, has no action.

Pure zinc is not readily affected by the ordinary pure sulphuric or hydrochloric acids, but small traces of impurities determine the solution of the metal, hydrogen being evolved. Ordinary commercial zinc, or spelter, as it is called in ingot, is readily attacked by these acids, and can decompose boiling water, giving off hydrogen. Zinc dissolved in hydrochloric acid constitutes the "spirits of salt" used as a flux in soft soldering.

At ordinary temperatures zinc is brittle, but heated to 100° to 150° C. it becomes malleable, and may be readily rolled and hammered. If raised to 205° C. it again becomes brittle, and may be readily reduced to powder. Zinc possesses the property of being readily deposited from solutions, and also that of depositing other metals from solution, such as gold in the cyanide processes, silver, and copper. It also lowers the melting-point of the metals to which it may be alloyed. The chief use of the metal industrially is as a constituent of alloys, and for galvanizing iron.

Dental Uses of Zinc.—1. As a die metal, either alone or alloyed with tin, etc.

2. As a constituent of gold solders to increase fluidity.

3. In dental amalgams chiefly as a substitute for platinum.

4. In the oxyphosphate, oxysulphate, and oxychloride of zinc cement fillings, and in several of its salts, as learned under Materia Medica.

5. In German silver, brass, silver solders, etc.

Zinc as a Die Metal.—The metal has long been a favourite for casting dies for swaging plates. Its cheapness, hardness, and the ease with which it can be melted in the ordinary laboratory furnace or Fletcher melting apparatus; its strength, fluidity, and the fact that it may be remelted many times, if ordinary care is exercised, without depreciation of its properties, have brought it into favour. Stress has been put upon the marked contraction of the metal as it cools, but it should be noted that this contraction is largely confined to the base of the zinc model, and also may be greatly reduced if the metal is not overheated, is kept clean, and poured at the proper temperature. Brass-moulders generally test the heat of the alloy by using a billet of wood. If the wood sizzles violently on being plunged into the metal, this is a sign of too great heat; when the wood causes no commotion, the pouring heat has been reached. Zinc may be tested by the same means with good results. Over-hammering is a common cause of change of shape of the die, and most of the striking up of the base-plates should be done before the die and counter-die are brought together. All traces of scum or oxidized zinc should be carefully scraped clear of the metal before pouring, and care should be taken to keep the metals zinc and lead separate when melting either.

CLEANING ZINC.—When zinc has become contaminated with lead, the metals may be partially separated by bringing the zinc to melting-point, and allowing the metals to cool slowly until set. The lead sinks, and may be chiselled from the zinc. Ordinary dirt may frequently be removed by throwing chips of old wax on to the molten zinc and setting fire to it. The surface should then be well skimmed before pouring the metal. Ammonium chloride used in the same manner yields good results. When the age of zinc affects its fluidity, hardness, and strength, the addition of 1 part aluminium to every 9 parts zinc, mentioned by Richardson, also improves the metal. The aluminium is melted, and added to the zinc and well stirred, and the surface ladled clear of débris. The aluminium reduces oxidation, and, when added in small quantities, does not reduce the strength of the zinc.

ALLOYS OF ZINC.

Brass.—Ordinary brass contains 30 to 40 per cent. zinc, and the balance copper. The proportions of these may vary, however, the name of the alloy also changing; thus, one form of brass is known as "yellow metal" in dentistry, but its fusing-point, rapid oxidation, etc., have led to its disuse.

Zinc and copper alloy readily, and besides brass and yellow metal, we have it in the following:

1. **Aich's metal** contains 60 per cent. copper, 1·8 per cent. iron, and 38·2 zinc.

2. **Muntz metal** contains 60 to 64 per cent. copper, 36 to 40 per cent. zinc.

3. **Electrum metal** contains 51·6 per cent. copper, 25·8 per cent. nickel, and 22·6 per cent. zinc.

4. **Tutenag** contains 45·7 per cent. copper, 17·4 per cent. nickel, and 36·9 per cent. zinc.

5. **Dutch metal**, or Dutch leaf-gold, contains 11 parts copper, 2 parts zinc.

British copper coins contain 1 per cent. zinc.

German Silver.—Copper 5 parts, nickel 2 to 3 parts, zinc 3·5 parts, constitutes German silver. (See Nickel.)

Zinc and Lead.—These metals when alloyed constantly tend to liquate. Lead softens zinc, and in small traces is added to commercial zinc to increase ductility.

Zinc and Tin.—These alloy readily, and in various proportions, showing little tendency to separate. Tin is added to spelter zinc for casting purposes, to overcome the brittleness of zinc when hammered ; to check contraction ; to increase the fluidity of the metal when molten ; and to give the casting a smoother surface. Fletcher advocates tin to be added 1 part to 2 parts zinc ; Richardson, 1 part of tin to 4 parts zinc ; while by others equal parts have been advocated.

The 25 per cent. tin gives excellent results, provided overheating is avoided. Zinc and tin in equal parts yield an alloy almost equal to brass in density ; but as the proportion of tin is increased, deterioration also increases after several meltings.

Zinc and Gold.—These metals are never alloyed without the addition of such metals as copper and silver. Added to gold of various carats, zinc increases the fluidity ; hence it is added to many gold solders. (See Gold and Zinc.)

Zinc and Silver.—Zinc is only added to silver, generally along with copper, to reduce the standard and the fusing-point of silver ; it is present, too, in all silver solders. The chief use of the metal, apart from what has been given, is as a constituent of cement fillings and dental amalgams.

CEMENT FILLINGS.—These fillings may be roughly divided into three groups—the oxychloride, the oxyphosphate, and the oxysulphate of zinc. They are prepared from the pure zinc oxide as a base.

The Powder.—The oxide is prepared by the combustion of pure zinc by heating it, exposed to the air to 1,900° F., producing the white flocculent powder already mentioned. It may also be prepared by heating the carbonate of zinc ($ZnCO_3$) to redness. If overheated, the resulting powder is yellow in colour instead of white, and is harsh and gritty. The flocculent powder is treated with nitric acid, and calcined at a white heat in fireclay crucibles having the covers luted in place to exclude the air. The calcining is continued for several hours, when it will be found that the powder has contracted considerably, is light yellow in colour, and slightly vitreous. It is then ground to a fine powder, sieved through fine cloth to insure fineness of grit, and bottled. Arsenic, lead, and chalk, are the most common adulterations found in commercial zinc oxide. Pure zinc oxide is soluble in dilute sulphuric acid, any lead and arsenic present being left as a deposit. To bring the powder to the various shades required for dental cements, pure titanium, native oxide of titanium, powdered rutile, ammonium and calcium phosphate, cadmium oxide, etc., are added. The oxides of aluminium, magnesium, and tin, and silica, ground glass borax, etc., are added to improve the wearing qualities.

Oxychloride of Zinc Cement.—The powder is pure zinc oxide, mixed with some of the colouring and vitrifying agents. The liquid is a solution of zinc chloride, and is prepared by deliquescing with distilled water, the proportions being 2 of chloride to 1 of water. This is allowed a few days to settle, when the clear liquid is decanted.

Feichtinger's* formula is 3 parts zinc oxide, 1 part glass powder, 50 parts zinc chloride (specific gravity = 1·5), to which is further added 1 part borax dissolved in the least possible quantity of water. This cement filling, like the others of the group, should be well spatulated with a nickel, ivory, or heavily plated steel spatula, as the plain steel tends to cause darkening of the fillings a few weeks after insertion. The oxychloride acts as an irritant to pulp tissue, and, being prepared white as a rule, its use is chiefly confined to lining pulpless and discoloured teeth. On account of its antiseptic properties, it is used as a root canal filling. As the cement is rapidly attacked by the oral secretions, it is never brought to the cavity surface, but covered with gold, porcelain, amalgam, or oxyphosphate of zinc filling.

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* Griffith's "Dental Metallurgy," p. 136.

Oxyphosphate of Zinc.—The powder is the same as for the oxychloride. The liquid is prepared by dissolving pure glacial-phosphoric (metaphosphoric) acid in distilled water, and evaporating the solution to a syrupy consistency. This cement is less irritating to pulp tissue than the oxychloride, and is the cement mostly used. It is less soluble in saliva than the oxychloride, resists attrition better, is extremely adhesive, and has many uses.

Oxysulphate of Zinc. — The powder is 3 parts zinc oxide to 1 part calcined zinc sulphate; the liquid containing gum arabic dissolved in water, with a trace of calcium sulphate. The use of this cement is generally limited to protecting nearly exposed pulps, and lining sensitive teeth to receive metallic fillings. It is also used to relieve sensitiveness during preparation of a cavity, reducing the painful symptoms if left in the cavity a few weeks. It is never inserted as a finished filling, being less permanent than the oxyphosphates. All cement fillings are benefited by a protective coating of varnish or white cement wax before complete hardening has occurred, which generally occupies two hours at the minimum.

Oxyphosphate of Copper.—The powder is pure oxide of copper plus some siliceous ingredients to increase the wear resistance. The liquid is similar to the oxyphosphate. The cement is almost black in colour, and is used only in fillings away from the front of the mouth. It offers greater resistance to the saliva, and wears better, than the oxyphosphate, and is of service in filling cavities in deciduous teeth, as a temporary filling in permanent molars, and in those troublesome cavities occurring on the buccal surface of wisdom and molar teeth. The cement sets rapidly, and the colour does not affect the colour of the tooth by impregnation.

SILICATE CEMENTS.—These fillings in their most recent forms present properties which render them valuable in many instances. As a class they are translucent when moistened by saliva and polished ; they offer fair resistance to attrition and normal saliva, and the wide range of colours permits of accurate colour matching to the rest of the tooth. It is urged against these fillings that they are less adhesive than the oxyphosphates, and that they contract. These failings, however, can be overcome to a large extent by making the cavity of a retentive shape, and by careful mixing, as in the case of oxyphosphate. They are best mixed on an agate slab kept solely for this filling, the spatula preferably ivory, agate, or good bone. The instruments used in inserting and shaping the filling should be of bone, ivory, agate, or tortoiseshell ; on no account should steel instruments be used for shaping, or steel burs in finishing, as they cause the filling to darken very markedly. The various varieties differ in composition, but they may be held to contain the following :

Powder.—A combination of basic beryllium nitrate, $Be(NO_3)_2 2BeO$, and sodium silicate ;* or a compound of silicates of lime and alumina with aluminates, modified by the addition of other basic silicates which the manufacturers may determine advantageous in the production of desired effects.*

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* *Dental Cosmos*, April, 1909, p. 442.

Liquid.—A solution of 52 per cent. orthophosphoric acid and an almost saturated solution of aluminium phosphate, with a trace of zinc or strontium phosphate dissolved in it.

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* *Dental Cosmos*, April, 1909, p. 440.

CHAPTER XIV

TIN

Symbol, Sn.	Atomic weight, 118·80.
Specific gravity, 7·30.	Melting-point, 232° C.

OCCURRENCE. — Cassiterite, or tinstone (SnO_2), the most important ore and source of the metal, is found in immense deposits, although in few localities. It is at times found in almost pure nodules of the oxide known as *stream tin ore.* It is usually associated with ores of arsenic, copper pyrites, specular iron ore, wolfram (tungstate of iron and manganese), and other minerals. It also occurs as tin pyrites (SnS), to a lesser extent.

PREPARATION OF TIN.—Commercial tin is prepared exclusively from the oxide or tinstone, the process consisting of—

1. Crushing the ore and washing it free of earthy matter.

2. Calcining in a reverberatory furnace to drive off sulphur as sulphur dioxide, and arsenic as arsenious oxide, which latter is collected by condensation.

3. Washing the calcined ore in wooden tanks, when copper sulphate dissolves out, and is deposited by iron plates as "cement copper." Oxide of iron and other light matters are removed as a scum.

4. *Smelting Process.* — The smelting of the tin ore

is generally carried out in a reverberatory furnace. The furnace charge consists of tin ore mixed with one-fifth its weight of powdered anthracite, a little lime or fluorspar being added as a flux to carry off any trace of silica present. The mixture is moistened to cause it to cake together, and the heat gradually raised for five hours. The slag as it forms is drawn off through tap-holes, carrying with it the silicates of iron, etc., and the furnace charge constantly stirred with billets of green wood. The tin is then run into iron receptacles called "kettles." Tin so produced contains traces of several metals contained in the ore, and has to undergo a process of refining.

Refining of Tin.—The process of separating the tin from the alloyed metals consists of liquation and poling.

Liquation of Tin.—The ingots produced by the previous process are heated on the bed of a reverberatory furnace until the melting-point of the tin is reached, when the metal melts and flows away, and is collected in pots, or, as they are called, "kettles," which are heated by a separate fire. Most of the impurities are left on the hearth of the furnace.

Poling of Tin.—The tin is kept at melting-point in kettles, and stirred with poles of green wood, or logs of wet wood are held under the surface of the metal. The steam evolved by the wood sets up a violent action, causing the impurities still present to be thrown out of combination with the tin; they collect as a scum on the surface, and are then skimmed off. At times "tossing" of the tin is resorted to instead of poling; that is, the tin is raised in ladlefuls and poured back into the kettle. The tin is run into moulds, and allowed to set slowly. The purest tin, known as *grain tin*, remains on the surface, and may be collected; the central layer is ordinary tin, and the bottom layer is generally put through the refining process again.

Blast-Furnace Process.—In Saxony the blast-furnace process is employed for the preparation of tin, the charge of ore, fuel, and flux, being similar to that in the process described above. The furnaces used are small, and the temperature is kept as low as possible, in order to prevent the reduction of other metals. The tin produced has to be liquated and refined. The loss of tin due to oxidation is rather higher than in the reverberatory furnace process.

When wolfram is present in an ore of tin, it is generally removed by special treatment. Soda ash and coal dust are added to the ore, and the mixture heated in a reverberatory furnace. Tungstate of soda is formed, which is removed by washing, and collected by evaporating the solution. The oxides of manganese and iron still in the ores are readily removed by further washing.

PROPERTIES OF TIN.—Tin is a white metal with a slight tinge of yellow, and when heated emits a peculiar odour. It is among the least tenacious of the metals, but is very malleable, and can be rolled, when pure, into very thin foil with ease. Tin in ingot or bar form shows a crystalline structure on fracture, and if a rod of tin be bent it emits a peculiar sound, referred to as the "cry of tin," due to the crystals of the metal grinding together. Rolling or hammering, while destroying its crystalline structure, does not appreciably increase the specific gravity. The name "grain tin," already mentioned, refers to the peculiar structure of the metal, which is produced by striking the metal with a hammer when on the point of setting, or by dropping a heated ingot from a height and breaking it, the crystalline structure being thus broken up.

TINNING OF IRON.—Tin does not oxidize at ordinary temperature or in moist air—hence its value as a protective coating to articles made of iron. This coating is referred to as "tinning," and is applied by cleaning the iron surface thoroughly with sulphuric acid and sand, drying thoroughly by dipping the article into molten tallow, then plunging it into melted tin. Several coatings are necessary to insure evenness of the surface.

Tin is an important constituent of many alloys, such as bronzes, etc. (See Alloys.) It is soluble in alkaline solutions—an important property from a dental standpoint. Strong nitric acid does not dissolve tin, but oxidizes it ; dilute nitric acid dissolves tin, nitrous fumes being given off and metastannic acid formed. The metal is also soluble in strong hydrochloric and sulphuric acids.

Tin may be deposited from its solutions in the form of elongated needles by electricity.

Putty Powder.—An impure form of tin dioxide, known as "putty powder," is produced by heating the metal beyond its melting-point. This powder, yellowish in colour, is largely used for polishing glass and for restoring the polish to artificial teeth, porcelain inlays, fillings, etc.

DENTAL USES OF TIN.—In the laboratory, tin is used in foil form for taking shapes for metal plates and making polishing plates ; in several thicknesses of foil, or in sheet, for try-in plates ; pure or alloyed with silver or gold for lower dentures, etc., or alloyed with a trace of lead for suction chambers ; and as a constituent of soft solders for special trays, etc.

As a Filling Material.—As a filling material, tin is used pure in foil or cylinders, in much the same manner as gold. It is less cohesive than gold, less malleable, and darkens when exposed to the saliva. The darkening, however, is not transmitted to the tooth structure, as with palladium amalgams. It possesses fair edge strength when not exposed to the full strain of mastication in a compound cavity ; does not contract ; is low in conductivity, and affords good protection to the tooth against caries. Cavities exposed to the full strain of mastication are frequently based with tin, and surfaced with gold, to afford greater protection. Tin has an important position as a constituent of dental amalgams. (See Amalgams.)

Casting Tin for Lower Dentures.—Tin is used either pure or alloyed (see Alloys) for casting lower dentures, where increased weight is necessary, or where the vulcanite seems to inflame the tissues. The process, sometimes referred to as the "cheoplastic process," is simple. The denture is carefully waxed up as usual, and the surfaces made as smooth as possible. It is invested in plaster of Paris, in one of the various forms of flasks supplied for the purpose, with the teeth facing upwards, and limiting the investment generally to a little beyond the line of the teeth. The surface is made smooth, and gates cut ready; the upper section of the flask is put in position, and the investment completed. The process is very similar to investing for vulcanite, using the lid or upper portion of the flask as the first part of the investment, or "upside down," compared with the investment of partial sets. The flask is thoroughly heated to dryness after the wax is boiled out and the gates cleared, the tin melted, the flask closed perfectly tight, and the tin poured through one of the gates. The denture is finished in the usual manner. The denture may be rapidly repaired by cutting out the piece required, and either pouring in fresh tin or placing small pieces of the metal on the part, and melting them with a hot spatula.

Alloys for this purpose should possess certain properties:

1. They should not discolour in the mouth.
2. They should be non-irritating to the mucous membrane and non-poisonous.
3. The fusing-point should not be very high, so as to reduce chance of fracture of the teeth in firing.
4. They should lend themselves to being rapidly repaired.

Bean's alloy for casting lower dentures: 95 parts tin, 5 parts silver.

Reese's alloy for casting lower dentures: 20 parts tin, 1 part gold, 2 parts silver.

Kingsbury's alloy for casting lower dentures: 16 parts tin, 1 part antimony.

Tin alloys readily with gold, but tin beyond 10 per cent. renders the gold brittle.

If alloyed with platinum or palladium, the alloy is hard and brittle. Silver and tin alloy readily, and an alloy of these metals containing 20 parts tin and 80 parts silver is tough, and is not brittle. Tin exerts a wonderful effect when alloyed with all these metals, lowering their fusing-points. The metal also has a wonderful affinity for gold and platinum, combining with explosive violence with platinum if the two are rolled together and melted under the blowpipe (Turner).

ALLOYS OF TIN.

Britannia metal (1) contains 42 parts tin, 3 parts antimony, 1 part copper, and 1 part bass.

Britannia metal (2) contains 90·7 parts tin, 7·8 parts antimony, 1·5 parts copper.

Pewter metal contains 12 parts tin, 3 parts antimony.

Gun metal contains 10 parts tin, 90 parts copper.

Speculum metal contains 33 parts tin, 67 parts copper.

Bronze contains copper, tin, and zinc, in varying proportions. (See Copper.)

British copper coinage contains about 4 per cent. tin. (See Silver.)

Meter metal, an alloy of tin and lead plus a trace of antimony, is used instead of tin-foil for swaging trial and polishing plates.

CHAPTER XV

CADMIUM

Symbol, Cd. Atomic weight, 111·70.
Specific gravity, 8·60. Melting-point, 320° C.

OCCURRENCE.—In the process of zinc extraction it was observed that a brown-coloured volatile vapour was in most cases distilled over with the first portion of the zinc. This, on examination, was found to be the metal cadmium. It is chiefly obtained as a by-product in zinc extraction, especially if zinc-blende and calamine are being reduced, when the yield is about 0·3 per cent. cadmium.

It is found as a native sulphide (CdS), containing 77·6 per cent. cadmium, and known as "greenockite" in Renfrewshire, Scotland.

PREPARATION.—Cadmium at the present time is only prepared by dry methods on commercial scales.

Extraction of Cadmium by Dry Method.—Advantage is taken of the fact that cadmium oxide is reduced to the metallic state at a lower temperature than zinc, and that cadmium also volatilizes at a lower temperature than does metallic zinc. The dust which passes over during the first two hours during the extraction of zinc is what is used, and is found to contain from 6 to 8 per cent. cadmium. This is mixed with coal, and heated in retorts to redness, the cadmium passing into long sheet-iron cones, where it collects. As this contains traces of zinc and zinc oxide, it is again mixed with charcoal, and distilled in small clay or cast-iron retorts fitted with long sheet-iron adapters, where the cadmium is removed in the metallic state. Pure cadmium may be obtained by dissolving zinc and cadmium in dilute sulphuric acid, and passing sulphuretted hydrogen through the solution, thus precipitating the cadmium as the pure sulphide. The sulphide is dissolved in strong hydrochloric acid, and carbonate of ammonia added. Cadmium carbonate is formed, which, distilled with charcoal, yields pure cadmium.

PROPERTIES OF CADMIUM.—Cadmium is a white metal with a bluish tinge, dense in structure, and crystallizes in the forms of the cubical system. The metal is soft and ductile, and can be rolled into very thin foil or drawn into fine wire. It is generally met with as rods about 3 inches long, which " cry " like tin when bent. Cadmium is soluble in hydrochloric, sulphuric, and nitric acids, the latter dissolving it rapidly. It is also acted upon by alkaline solutions, and sulphuretted hydrogen acts on the metal, forming cadmium sulphide.

Cadmium added to amalgams hastens the setting, also rendering them more plastic. It was formerly used in dental amalgams; but the blackness of the resulting filling, the formation of cadmium sulphide on the surface, and the solvent action of alkaline solutions on the metal, led to its disuse.

Its chief use at present is as a constituent of the fusible metals. Added to alloys, cadmium possesses the property of lowering the melting-points to a remarkable degree. Thus, an alloy containing 8 parts lead, 15 parts bismuth, 4 parts tin, and 3 parts cadmium, melts at 60° C., and is quite fluid at ~~70~~ 65° C.[*]

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[*] Lipowitz, Dingler, vol. clviii., p. 376.

Cadmium has lately been used for electro-deposition as an alloy with silver in place of ordinary silver-plating.

For other alloys, see Fusible Metals.

BISMUTH

Symbol, Bi.	Atomic weight, 207·50.
Specific gravity, 9·80.	Melting-point, 268° C.

OCCURRENCE.—This metal occurs native to a considerable extent, native bismuth being, in fact, the chief source of bismuth.

Bismuth ochre (Bi_2O_3) contains 87 per cent. bismuth, with traces of arsenic, copper, and iron. Bismuth glance (Bi_2S_3), the sulphide, contains 81·25 per cent. bismuth.

Bismuth copper glance ($3Cu_2S + Bi_2S_3$).

PREPARATION.—Bismuth is extracted by dry and wet processes, the electrolytic process not having yet been adopted to any great extent.

Dry Methods—Extraction of Bismuth by Fusion Processes.—The bismuth is either separated by liquation or fusion. Of these the fusion process is more complete, admitting of the addition of reducing or desulphurizing agents, which, while removing the metallic bismuth, also extract the bismuth and sulphur and the bismuth compounds. Crucible furnaces are generally employed in the fusion process; carbon is added to reduce the oxides, iron to absorb the sulphur, and an alkaline flux to combine with any gangue present. The bismuth is melted and poured into iron moulds. The metal collects at the bottom, covered by a speiss containing arsenic, nickel, traces of cobalt, and the slag, from which the bismuth is run off, the speiss and the slag setting more rapidly.

Extraction of Bismuth by Wet Method from the Ore.*—The ore is first toasted to drive off the arsenic and sulphur and, transferred, while hot, from the furnace to wooden troughs, where it is dissolved in dilute hydrochloric acid. The oxychloride of bismuth so formed is precipitated by the addition of water. If any lead or iron is present, the precipitate is again dissolved in dilute hydrochloric acid, and precipitated with water. The precipitate is washed, dried, and mixed with charcoal, slag, and some lime. The bismuth may also be precipitated from the hydrochloric acid solution by metallic iron. It is then melted in graphite crucibles, producing metallic bismuth.

PROPERTIES OF BISMUTH.—Bismuth is grey-white in colour, with a decidedly reddish tinge and a bright metallic lustre, which is not affected by exposure to the atmosphere. The metal is rapidly oxidized by heat, and, at a temperature above its melting-point, burns with a bluish flame, giving off yellow fumes of the "flowers of bismuth," a property also possessed by antimony. Bismuth is extremely brittle, and can be readily reduced to powder. Like antimony, it crystallizes in rhombohedrons, is strongly diamagnetic, possesses the peculiar property of expanding when cooling, and has a higher specific gravity when liquid than when solid. It is vigorously attacked by nitric acid, bismuth nitrate being formed, which, diluted with water, forms the insoluble basic nitrate of bismuth. The impurities present in the metal are traces of arsenic and sulphur, also copper, cobalt, gold, silver, and nickel, the silver having been found present in as high a proportion as 60 ounces to the ton.† The brittle quality of the metal prevents its separate use. Advantage is taken of this property of expanding on cooling, its low fusing-point, and its consequent lowering of the fusing-points of the alloys to which it is added. It is added, for example, to type metal and stereotype metal, because of its property of expanding on cooling, as it gives a much finer casting owing to the absence of any contraction. It is made use of mostly in the group of low fusing-point alloys known as "fusible metals," which are dealt with in another chapter. Bismuth added to gold or silver renders the metal brittle and unworkable. Added to lead in the proportion of 3 parts of lead to 2 parts of bismuth, it yields an alloy said to possess ten times the strength of lead. The action of the metal, like antimony, is to harden whatever metal it may be added to. It is never added to dental amalgams, as it increases the quantity of mercury required to form the amalgam, besides imparting to it a sticky quality. Fletcher states that an amalgam of 1 part bismuth, 15 parts tin, 15 parts silver, fused, filed up, and mixed 1 part alloy to 4 parts mercury, will adhere to a flat dry surface, and may be used as a metallic cement for joints in apparatus which require to be perfectly air-tight and stand heavy pressure.

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* *The Mineral Industry*, 1896, p. 55.

† Greenwood.

Bismuth is contained in some forms of Britannia metal, Queen's metal, and in the solder used for pewter.

ANTIMONY

Symbol, Sb.	Atomic weight, 120·00.
Specific gravity, 6·71.	Melting-point, 445° C.

OCCURRENCE.—Antimony glance (Sb_2S_3), the sulphide, is the chief source of the metal. It is also known as "grey antimony ore," "antimonite," and "stibnite." It contains about 71·77 per cent. antimony and 28·23 per cent sulphur.

Oxide of antimony (Sb_2O_3), also known as "white antimony ore" and "antimony bloom," contains 83·4 per cent. antimony and 16·6 per cent. oxygen. It is formed by weathering of the sulphide or of native antimony, and is less abundant than the sulphide.

Red antimony ore ($2Sb_2S_3 + Sb_2O_3$), also known as "antimony blende" or "pyrostibnite," contains 75 per cent. antimony. Antimony ochre, or cervantite (Sb_2O_4), native antimony, etc., are even less abundant sources of the metal. Antimony is also found present in many of the nickel, lead, silver, and copper ores.

PREPARATION.—At present the dry methods alone are employed for extracting antimony from the ore, the wet methods and the electro-metallurgical processes not having as yet found practical application.

The ore used most frequently is the sulphide, and advantage is taken of the comparatively low fusing-point of antimony to liquate the metal. The ore is seldom reduced further than pieces of walnut size, the finer the ore is ground the less complete being the separation. The liquation is effected either in pots, reverberatory furnaces, or tubes, the temperature being kept as near the liquating-point of the metal as possible. As the antimony melts, it is collected as a form of crude antimony containing an excess of sulphur. It is then mixed with twice its weight of scrap iron or iron filings enclosed in cone-shaped crucibles, and heated to a higher temperature. The sulphur combines with the iron; the antimony fuses, and is tapped off. Or the purified sulphide may be heated to form the oxide, which in turn may be reduced by charcoal.

PROPERTIES.—Antimony is bluish-white in colour, with a brilliant lustre; is crystalline and brittle, being readily reduced to powder by hammering. It crystallizes in the rhombohedral system, the surface of the metal exhibiting characteristic fernlike markings. The metal is slowly volatilized if raised to a white heat and exposed to an atmosphere of hydrogen. It is not sensibly affected by ordinary temperatures, or even in the atmosphere, but at a red heat burns with a bluish-white flame, the oxide (Sb_2O_3) being formed. Weak sulphuric acid has no action on the metal, but if heated with strong sulphuric acid the sulphate is formed and sulphurous anhydride given off. Hydrochloric acid has no action on the metal in the mass, but when added to the powdered metal hydrogen is evolved. Nitric acid causes the metal to oxidize rapidly, but does not dissolve it. Antimony generally has a hardening effect if added to or present in another metal, and causes it to expand slightly on cooling. Its chief use in dental metallurgy is in an important series of alloys used as dies and counter-dies. The salts of antimony being poisonous, the metal is never added to dental amalgams.

ALLOYS OF ANTIMONY.

Type Metal.—1. Antimony 25 parts, lead 75 parts.

2. Antimony 18 parts, lead 70 parts, tin 10 parts, copper 2 parts.

3. Antimony 1 part, lead 8 parts, tin 1 part.

Either of the above alloys, especially that containing tin, makes a useful alloy for dies and counter-dies. It is especially useful for counter-dies, as, being harder than lead, there is less chance of spreading or distortion of the counter-die during the swaging of base-plates, etc. The alloy melts at a lower temperature than zinc, and, besides showing a constant tendency to liquate, has to be very carefully heated to prevent driving off the antimony. The alloy containing no tin is more brittle, and, when employed as a die, should be struck as seldom as possible. This alloy discloses no tendency, when freshly made, to contract.

Babbit Metal.—Antimony 22·3, copper 11·1, tin 66 per cent. Another formula is given in Turner's "Prosthetic Dentistry." Its contents are given as antimony 8, tin 24, copper 4.

Haskell's Metal.—Antimony 2 parts, tin 8 parts, copper 1 part.

Fletcher's Metal.—Antimony 17·64, tin 70·60, copper 11·76 per cent.

Pewter.—Antimony 15, lead 6, tin 79 per cent.

Antimony is also present in Britannia and Queen's metal, and in many of the fusible metals.

Antimony added to gold 0·05 per cent. renders the gold brittle and unworkable. Added to iron, 0·1 to 0·3 per cent. renders iron both cold and red-short.

Die Metals — Babbit Metal.—There are several formulæ for this useful alloy. In preparing the alloy, half the tin is melted, the antimony, then the copper added, and lastly the rest of the tin. The alloy is whitish in colour, almost like German silver, and has a lower melting-point than zinc. Compared with zinc, there is less contraction, and a cast of this alloy withstands more swaging without change of shape. The alloy should be carefully melted at each heating, and never allowed to reach a red heat, as the tin and antimony are oxidized, and the properties of the alloy completely altered. In casting the alloy, it should be well stirred before pouring, to insure the complete mixing of the component metals. Expense is greatly against the use of this alloy, besides which the constant tendency of the metals to separate is troublesome. When lead is used as a counter-die, the die of Babbit metal should be well coated with a thick paste of whiting to prevent the lead softening the surface of the die, and the lead heated to fusing-point, and no further. The alloy is made use of industrially for certain classes of bearings, etc.

Spence's Metal is a non-metallic compound containing the sulphides of iron, lead, antimony, and zinc, dissolved in sulphur. The proportions of these metals vary according to the purpose to which the compound is put. Thus, for dental use it is generally the sulphide of iron dissolved in an excess of sulphur. In colour it is black, is very brittle, melts at a low temperature, shows no contraction on setting, and, if carefully treated, remains stable in composition for a long time. It may be used for the finishing die in metal work, and gives the best results when used with some form of swager. It is also useful for casting impressions for fused porcelain inlays where the matrix has to be swaged to the cast. It sets rapidly, is sufficiently strong in the edges, and flows well. The brittleness of the compound is against its general use, and overheating drives off sulphur, thus reducing the strength of the compound for die purposes.

Brass.—This alloy was formerly used for dies, but its high melting-point, the constant tendency of the metals to separate, and the deterioration caused by frequent heatings, led to its disuse. Zinc either as spelter zinc or with 10 per cent. aluminium added is mostly employed for dies in metal work. (See Zinc.)

Lead as commercial lead, or with an addition of tin, is chiefly employed as the counter-die. The addition of tin helps the lead to retain its shape during the swaging, and renders the metal more fluid. (See Lead and Tin.)

FUSIBLE METALS.—The term " fusible metal " has come to be associated with a group of low fusing-point alloys, used for purposes such as—

1. For dies and counter-dies in ordinary gold-plate work.
2. For casting directly into impressions, in cases where an absolutely rigid and accurate model is necessary, as in bridge and crown work.
3. For casting dies for metal crown tops, where crowns are made in two pieces.
4. For dies in ordinary vulcanite work, where the tin try-in plate is swaged to the die.
5. For weighted lowers casting by gravitation.
6. For weighted lowers casting under pressure.
7. For effecting temporary repairs in dentures.
8. As safety plugs for vulcanizers.

These alloys generally contain tin, bismuth, lead, and cadmium, and for weighted lowers, tin, silver, and gold.

The following list gives the contents of several of these alloys for die and counter-die purposes, etc. :

Name.	Bismuth.	Tin.	Lead.	Cadmium.	Melting-point, ° C.
Molyneaux's alloy ..	5	2	3	2	60
Lipowitz alloy ..	15	4	8	3	65
Wood's alloy ..	5	2	4	2	71
Lichtenberg's alloy ..	7	7	13	2	75
Rose's alloy	8	3	8	—	79
Crouse's alloy ..	8	5	5	1	88
Newton's alloy ..	8	3	5	—	95
Fusible alloy	3	2	—	1	95
Brophy's alloy ..	12	10	11	—	98
Fusible alloy	48	26	19	13	158
Fusible alloy	4	12	15	—	172

These are all useful alloys, provided care and discrimination is exercised in using them.

These alloys are easily prepared by bringing the metals together and melting in a well-tempered crucible under a layer of charcoal, and well stirring together with a piece of wood. Mercury is at times added to the alloys employed as dies and counter-dies to still further reduce the melting-points.

Besides being useful for the purposes detailed above, they are of great service in tempering delicate-pointed instruments, or where great accuracy in the temper is required. The instrument to be tempered is laid on a block of an alloy whose fusing-point coincides with the temperature best suited for the instrument, and heat is applied. When the alloy melts, the instrument is withdrawn and cooled. (For temperatures for tempering, see Steel.) They are also used as safety-plugs for vulcanizers, steam-boilers, etc., and usually as an additional check on the steam-gauge or governor. Should the temperature rise too high, and the gauge or governor fail to act, the alloy, being in direct communication with the steam-chest, melts when its fusing-point is reached, letting free the steam.

These alloys have a marked tendency to separate on cooling, and give better results if they are melted under charcoal, and well stirred each time they are brought to the fusing-point.

CHAPTER XVI

ALLOYS

WITH the exception of gold, platinum, and aluminium, there are few metals used in dental metallurgy in the pure state; the metals used are generally in combination with one or more metals, this combination being known as "alloying." Metals as a rule are too soft for general purposes when in the pure state; therefore they are alloyed or mixed with another metal or metals to increase the hardness. The cost of such metals as gold, platinum, and iridium, also leads to their being alloyed, to reduce cost of production. The results of alloying generally are best studied if the effects on the general physical properties are considered.

PHYSICAL PROPERTIES OF ALLOYS.

Hardness.—Alloys generally are harder than any of the metals composing them. Examples: The alloy of gold, silver, and copper, as in the reduction of the carats of gold; the gold and platinum alloys used for clasps, etc.; copper and tin, as in the bronze alloys, the alloy possessing great hardness, and, in some of the old specimens used for weapons, good edge strength.

Fusibility. — Alloys generally possess lower melting-points than the metals composing them. Examples: The reduction of the carat of the gold reduces the melting-point; the group of fusible metals. Wood's fusible metal is composed of bismuth, lead, tin, and cadmium, and melts at 71° C.; while the lowest fusing-point of the component metals is tin at 232° C.

Colour.—The colour resulting from an alloy generally is what would be expected—namely, a mixture of all the colours contained in it. Examples: Silver added to pure gold whitens the gold; copper added to gold reddens it; hence, in alloying gold, the metals silver and copper are nearly equally balanced in quantity, the one overcoming the effect of the other on the resulting colour. *While this is true generally, there are some notable exceptions.* For instance, if 39 parts of gold are added to 11 parts of aluminium, an intensely ruby-coloured alloy results; equal parts of copper and antimony yield a violet-coloured alloy known as "the regulus of Venus"; while zinc and varying proportions of lead and tin added to copper yield alloys of various shades of velvety brown.

Density.—Alloys seldom possess specific gravities equal to the mean density of the metals combined in them. Expansion of an alloy on setting reduces the density, as, for example, in the union between gold and silver, gold and copper. Again, contraction on setting increases the density, as is seen in the union between gold and tin, gold and zinc, silver and tin, copper and tin, and copper and zinc.

Specific Heat.—The specific heats of alloys are generally the mean of the specific heats of the constituent metals.

Malleability and Ductility.—These properties are powerfully influenced by alloying, the result generally being a decrease in one or both of these properties. **The malleability and ductility of an alloy, however, cannot be reckoned from the mean average possessed by the constituent metals of the alloy.** For example, gold, a soft metal, alloyed with a trace of lead, another soft metal, yields an alloy which is brittle and unworkable. Again, gold, platinum, silver, and copper, all soft and malleable metals, yield alloys whose malleability and ductility are generally less than that of the metals when unalloyed. The best selected copper, alloyed with $\frac{1}{1000}$ part of antimony, is converted into the worst conceivable.*

The effect of alloying generally being to increase the hardness, the malleability is correspondingly reduced.

Tenacity.—This property is generally increased by alloying, the results in some cases being remarkable, and bearing no relation to the mean average of the metals alloyed.

Mathiessen's table, drawn from experiments made with wires of the same gauge, and made to withstand the same strain before and after alloying, gives as follows :

UNALLOYED.	Pounds at Rupture.	ALLOYED.	Pounds at Rupture.
Copper	25 to 30	Copper plus 12 per cent. tin ..	80 to 90
Gold	20 ,, 25	Gold plus copper ..	70
Silver	45 ,, 50	Silver plus platinum	75 to 80
Platinum	45 ,, 50		

Conductivity.—This property in alloys is generally much below that of the pure metals. For example, copper with an addition of silver has its power of conducting heat and electricity much reduced, even although silver stands very high in this property ; while the addition or presence of a small quantity of bismuth causes copper almost entirely to lose this property. Again, pure gold, when inserted as a filling, conducts thermal changes with great rapidity to the pulp tissue. This property is very much reduced when gold is alloyed with such metals as silver, copper, and tin, and amalgamated ; or when the gold is inserted as thin ropes of foil intermixed with tin-foil. Although this last combination is not introduced as an alloy (it being understood that some form of fusion or intermingling of the metallic molecules is essential in the formation of an alloy), the tin in this instance exerts its lower conducting power even when in contact with gold.

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* Sir Hussey Vivian.

Expansion by Heat.—**Alloys when heated generally expand in a degree very closely approximating to the ratio of the relative volumes of their constituents.**

Oxidation. — **Alloys are generally more readily oxidized than their constituents.** This is seen, for example, in the various carats of gold. Aluminium, on the other hand, is capable of exerting peculiar influences; added to steel and iron, it reduces the rapidity of oxidation. Zinc as used for dies oxidizes rapidly if overheated, even when brought to melting-point frequently; but the addition of 10 per cent. aluminium reduces this tendency towards rapid oxidation very considerably. Aluminium itself in the mass has no tendency to oxidize, but in a finely divided condition its affinity for oxygen is extremely great; but if coated with a thin layer of mercury it oxidizes rapidly, and is soon covered with a white film of alumina, which may be readily detached in flakes. Pure gold and pure platinum do not oxidize at ordinary temperatures; yet the alloys of the metals when worn in the mouth for some time, either as gold and platinum fillings, gold plates, crowns, or clasps, become oxidized superficially.

Decomposition.—Alloys containing volatile metals such as mercury, zinc, antimony, etc., are readily decomposed by heat. Amalgams, for instance, when heated to redness, yield ~~the~~ most of the mercury mercury, etc., and are readily reduced to powder. Other metals which enter into more intimate contact when alloyed are not so readily decomposed. Amalgams will yield all the mercury and zinc if heated to a bright red for some

Jenckel

minutes; but where gold is contaminated with lead or alloyed with tin, entire separation by using heat alone is impossible, the addition of potassium nitrate being necessary to effect this removal.

Sonorousness.—This property is developed by many metals only when alloyed. The bronzes, for instance, possess this property, yet tin, the chief constituent, does not possess it to any extent. Aluminium, though possessing this property only after special treatment in casting, is much improved in sonorousness if alloyed with silver or silver and copper.

Action of Acids upon Alloys.—The action of acids upon alloys generally is to dissolve out the excess of any metals which they attack as single metals, the action, however, generally being more pronounced. Advantage is taken of this in the parting process by sulphuric and nitric acid used in the treatment of purifying of gold. Other alloys, again, such as of silver and platinum, when silver is present beyond the "content" of platinum, are attacked by nitric acid, the platinum passing into the solution, although the acid has no action upon the platinum alone. Each alloy in many ways is best studied for its properties by itself, and the text-book written by the late Sir W. Roberts-Austin, "An Introduction to the Study of Metallurgy," gives much valuable information on the subject. (See "Alloys," by Edward F. Law.)

From the foregoing it will be seen that alloys as a class present some peculiar properties. When it is remembered that metals are capable of behaving, in all essentials, in the same manner as liquids, these properties will not present the same difficulties. All the metals are solid at ordinary temperatures, with the exception of mercury, which becomes solid only at − 39° C. Heated to their fusing-points, they become liquid, and behave while in this state as a liquid, intermixing with another metal or metals, occluding gases, etc. If heated beyond this point, the metals volatilize, passing off as a vapour, in much the same manner as water being converted to steam; and from the vapour they may be recovered again to the metallic state by cooling. This briefly outlines what changes occur with metals as a class. In the same manner the analogy can be carried farther when the alloying of the metals is considered. Mathiessen has described the conditions under which alloys are formed, and they may be grouped as follows:

1. An alloy may be a solidified solution of one metal in another. Gold & copper
2. An alloy may be a chemical mixture. Aluminium bronze
3. An alloy may be a mechanical mixture. lead & tin & zinc
4. An alloy may be a solidified solution or mechanical mixture of two or all of the above. [illegible]

Certain metals, such as copper and gold, exhibit a certain affinity for each other, the union being accompanied by a slight elevation of temperature. Repeated remeltings fail to disclose any tendency on the part of these metals to separate, and even when digested in acid the copper is removed only with difficulty. The same phenomena is found in the union between gold and silver, copper and aluminium (as in aluminium bronze, etc.), these alloys exhibiting physical properties in many instances widely different from those of the metal composing them, and confirming the now accepted opinion that, under certain conditions, definite chemical compounds are formed.

Other metals again, when alloyed, never exhibit any tendency to combine, and, from the first time they are brought into intimate contact by fusion, they constantly disclose the tendency to separate on cooling, such as the alloys of zinc and lead, and tin and lead. Such alloys behave exactly as some liquids do under certain conditions, and seem to be as incompatible as oil and water. Some of the more complex alloys, such as Babbit metal, used to a limited extent for dies in metal-work, occupy a position between the two classes mentioned—namely, between a mechanical mixture and a chemical compound. Babbit metal brought to the liquid state, and allowed to cool slowly without stirring, will be found on examination to have crystallized out largely in layers of metals, according to their specific gravities ; while on the surface there is an alloy of the component metals, but their proportions in this alloy will be entirely changed. Such an alloy may be grouped under Mathiessen's fourth classification.

Then, it is known that certain metals have a solvent action upon other metals, as exampled under the chapters on Mercury and Gold, and Mercury and Silver. Mercury in this instance behaves in the same manner as a liquid solvent, removing the gold and silver from combination with other metals ; the gold and silver may then be separated by driving off the mercury by heat. Lead, again, has a strong affinity and solvent action upon silver, and advantage is taken of this property of lead in the removal of silver from some of its ores. (See Pattison Process.)

The proportions in which the metals are brought together plays an important part in the behaviour of the alloys, it having been found that metals possess combining powers in the same way as liquids. In aluminium bronze, for example, the proportions of aluminium seldom exceed from 5 to 10 per cent. When the aluminium is increased beyond this, the alloy loses many of its valuable physical properties, such as resistance to alkaline solutions, strength, and tenacity ; possesses a lower fusing-point, and oxidizes excessively when being soldered. The alloy of gold and platinum, as used by some operators as foil or matt for filling purposes, is composed of the two most malleable metals ; yet when platinum beyond the small proportions used is added, the alloy loses the valuable property of cohesiveness, and discloses a tendency to discolour in the mouth. This question is more fully dealt with as far as alloys are amalgamated for filling purposes, but the field before experimenters is a wide one and one full of great interest.

PREPARATION OF ALLOYS—By Fusion.—Alloys of the noble metals are generally prepared by a process of fusion, and may either be formed simultaneously, or the metal possessing the highest melting-point melted, and the others introduced in their order. It is found, in preparing alloys of pure gold and platinum alloyed with silver and copper, that, if these metals be melted simultaneously with the gold or platinum, the alloy is melted at a much lower temperature than if the metals were melted separately. This fact is especially useful in preparing alloys of platinum, as they can be prepared by using the ordinary furnace heat, or even using a Fletcher furnace.

In all cases alloys for dental purposes should be prepared from pure metals.

When noble and base metals are to be combined in an alloy, the same rule holds good; and to avoid oxidation the metals should be covered with a layer of powdered charcoal during the heating and melting. Where such volatile metals as zinc and antimony are being added, even although only in traces, the alloy should be allowed to cool to near setting-point before they are introduced, the alloy being then well stirred and poured. The practice of melting alloys under a layer of borax is generally only applicable to those containing noble metals. The action of the ordinary commercial borax upon base metals is to induce loss by oxidation, and by solution or absorption of some of these in the borax glass.

Where alloys are prepared on a small scale, crucibles are generally employed. They should be well tempered before using, and the sides coated with borax and thoroughly glazed before receiving the alloy, as there

[illegible] Borax [illegible] crackles [illegible] the
oxidation of [illegible] metal in heating for

is loss of metal through some of it passing into the body of the crucible if this is neglected.

By Compression. — In alloys composed entirely of base metals, it has been found practicable to prepare these by compression. Professor Walthère Spring, of Liége University, prepared one of the fusible alloys composed of 15 parts bismuth, 8 parts lead, 4 parts tin, and 3 parts cadmium. The metals were finely divided, enclosed in a steel cylinder with an accurately-fitting piston of steel, and compressed. The block of alloy so produced was again reduced to powder and again compressed, giving an alloy which melted at 98° C., the same temperature as that generally produced by fusion, although the lowest melting-point of the constituent metals is that of tin at 232° C. Advantage may be taken of this means of preparing alloys composed chiefly of metals which are either volatile or readily oxidized, as by this means there is absence of loss of weight due to these causes.

Eutectic Alloys.—Alloys of the same metals, but in different proportions, generally possess different melting-points ; and the alloy having the lowest melting-point is known as the "eutectic" alloy of that series ; examples, many of the fusible alloys.

UNION OF METALS BY ELECTRO-DEPOSITION.—The Japanese bronzes and alloys so largely used for art purposes can be prepared by electrolysis, as can also brass from copper and zinc, from the mixed cyanides of copper and zinc, dissolved in a solution of cyanide of potassium. The process has been successfully employed in the preparation of silver and gold alloys, in the treatment of compound ores, etc. ; but so far no literature is available to show that the process has been employed in the preparation of alloys used in industry or dentistry.

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CHAPTER XVII

DENTAL AMALGAMS

AMALGAMS for dental purposes are generally confined to those suitable for inserting as fillings, and consist of various alloys amalgamated with mercury. Many years ago, when amalgams were introduced, they generally consisted of one metal, such as copper or silver, reduced to powder and amalgamated with mercury immediately before insertion. By many of the profession the use of such materials was regarded with little favour, and it is only within comparatively recent years that the uses of amalgams have been recognized and appreciated, and their proper sphere mapped out and limited. It is generally recognized, for instance, that gold as an all-round filling material still holds the premier position ; and where the operator recognizes that the cavity is one into which any material could be inserted with accuracy, then that cavity should be filled with gold.

Amalgams are generally limited to restorations in cavities in deciduous teeth, especially in the molar region ; in cavities in the permanent teeth not readily accessible, where the insertion of gold would incur too severe a strain on the patient ; where the tooth is too frail to withstand the malleting necessary for gold ; and where the difficulties attending the keeping of the cavity perfectly dry are too great. In many instances a useful combination of gold and amalgam is employed in those cavities where caries has attacked the tooth deep below the gum level. In such positions, the portion of the cavity situated below the gum level may be restored with amalgam, which, after being allowed a day or so to set, is carefully polished, and the rest of the cavity filled with gold. The amalgam in such positions must never contain excess of free mercury, as this would attack the gold, causing it to discolour, and fray on the surface so attacked. The practice of coating the amalgam in these cavities with several layers of thin gold-foil, as advocated by Dr. Ottolengui, is to be recommended. The amalgam is left a little short of the cavity edge and short of the contour desired, and with hand burnishers the gold-foil is laid over the surface and burnished to position while the amalgam is still soft. The mercury attacks the gold for several layers, but the surface is homogeneous ; there is no excess left to attack the gold inserted in the rest of the cavity, and the filling remains a good colour. This has come to be advocated by many operators, as it benefits the contouring with amalgams in all positions. In addition to the effect of the gold already mentioned, the filling is harder before the patient leaves the chair, the contouring to the bite can be done with accuracy, and there is less chance of change of shape of the filling, caused by the patient masticating with the tooth before the filling has quite set. With the probable exception of gold, amalgams are the most useful materials at the command of the profession at the present time. As a class, they may be considered to possess the following properties :

1. They are readily inserted, being more or less plastic, and on this account can be made to fit closely to the cavity walls.

2. They possess great edge strength, being hard and not liable to fracture, and large contours can be safely built with them to replace lost tooth tissue.

3. They resist attrition, are not soluble in saliva, and, perhaps with the exception of Sullivan amalgam, do not stain the tooth.

4. They do not readily oxidize in the mouth, the oxidation being entirely superficial.

These are, broadly speaking, the properties possessed by dental amalgams as a class; and although few, if any, of those in use possess the properties mentioned in the superlative degree, they may be held to possess them comparatively.

An ideal amalgam, on the other hand, should possess the following properties:

1. It should be readily inserted with accuracy, and not tend towards friability when burnishing pressure is applied.

2. It should be insoluble in the saliva, and should not favour the formation of any salt injurious to the tooth structure or health of the patient.

3. When hard it should be unalterable in shape, presenting neither expansion nor contraction, and not liable to change in shape when subjected to the force of mastication.

4. It should continue to possess good colour, and not be liable to oxidation in the mouth.

5. It should not act as an irritant to the pulp when inserted within reasonable distance of that structure, either by electrical conductivity, by conducting thermal changes, or by reason of the properties of the metals contained in it.

6. It should harden moderately fast, and thus lessen the chances of change of shape.

7. It should not stain the tooth structure, and, when polished, its colour should not render it conspicuous in relation to the rest of the tooth.

8. It should amalgamate freely and thoroughly, and should possess a definite combining weight with mercury.

It will be seen that no amalgam at present possesses all of these properties. For many years now the endeavour has been to prepare amalgams, for instance, which would show a slight expansion after setting, the idea being that this expansion would bring the filling into closer contact with the cavity walls, and so exclude bacteria. Many amalgams certainly possess this property to a marked degree, but it has not been shown that this expansion is always in the line the operator most desires. In large contours restored by amalgams, the expansion, after several months or a few years, seems to be from a common centre. The result is that the edges of the cavity are left unprotected, even although the filling itself draws attention to the expansion which takes place, by impinging on the bite if situated on a grinding surface. What the operator should seek for is an amalgam which will remain exactly as it is after the filling is polished. Expansion of an accurately inserted filling is unnecessary ; and even although the expansion were to take place in the line desired, many teeth would be too frail to withstand the additional pressure exerted on the cavity walls.

With the exception of the amalgam of copper and mercury (already referred to in the chapters on copper and mercury, and known as "Sullivan filling" or "copper amalgam "), all the other metals are employed as alloys, the mercury being added to the alloy, which is either in the form of fine filings or shavings. As separate metals, they all exhibit some property which probihits their use in this form.

Gold added to mercury amalgamates well, being soluble in an excess of mercury, but does not harden sufficiently, and does not possess sufficient edge strength, besides contracting excessively.

Platinum requires an excess of mercury to render the amalgam plastic, does not harden well, lacks edge strength, and contracts.

Silver amalgamates well, the union of the metals being accompanied by evolution of heat; but fillings of this amalgam expand excessively, and discolour the tooth through oxidation.

Tin amalgamates readily, but never hardens sufficiently. - contracts.

Zinc, although a constituent of many dental amalgams, is never used alone combined with mercury. - takes place of platinum.

Palladium amalgamates readily; becomes fairly plastic, the union of the metals being accompanied by a rise in temperature. The amalgam, however, discolours, and the prohibitive price of palladium, due to its scarcity, has led to its disuse.

Although the separate metals exhibit these properties when amalgamated with mercury, they also produce certain definite effects if added as constituents of alloys. Thus—

Gold improves the working qualities of an amalgam, renders it more plastic, slows the time of setting, improves the edge strength, counteracts shrinkage, and improves the colour by counteracting oxidation.

Platinum counteracts oxidation, hastens the setting, increases the edge strength, overcomes the tendency to change of form after setting, but increases the amount of mercury required.

Silver increases the edge strength and rigidity, counteracts contraction, and reduces the amount of mercury required. This metal, however, increases oxidation.

Copper increases the strength, counteracts contraction, hastens the setting of the filling, and by some authorities is held to exert a therapeutic effect on the tooth, by depositing the antiseptic copper sulphate in the dentinal tubules.

Against this it might be stated that several teeth showing the blue-black stain denoting copper have been tested, and no free copper sulphate found; while the advocates of copper can point to many instances where arrested decay has been discovered impregnated deeply with the stain of copper. It is now generally accepted, however, that staining beneath the free margin of an amalgam filling is due to the ingress of particles of food and moisture, and should be traced to contraction or change of shape in the filling, and not to any inherent protecting virtue in the amalgam.

Tin amalgamates freely, rendering the amalgam more plastic, but exerts a contracting effect, besides counteracting the expansion produced by the addition of silver.

Dr. Black made careful researches into the composition and behaviour of dental amalgams from the scientific standpoint, and his results have advanced the knowledge and preparation of these from the region of chance and guesswork towards that of scientific knowledge and accuracy.

He confined his experiments chiefly to the study of the combinations of silver and tin in various proportions, only adding the other metals to modify certain effects. His results led him to declare that "no advantage whatever is derived from adding gold or platinum to alloys, but so long as these are used very sparingly they do not do much harm. Copper, not more than 5 per cent., if alloyed with the silver before combining with the tin, so as to insure a perfect alloy, increases the strength of the amalgam without doing injury in other ways, and seems desirable. In my present view it is the only modifying metal thus far known that is desirable."*

Fletcher, on the other hand, advocated the use of platinum for hastening the setting, enabling the amalgam to retain its form, and attributing the dirt left in the hand after amalgamating the alloy to the perfect fit produced by the addition of platinum.*

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* Black, "Operative Dentistry," vol. ii., p. 312.

The table on p. 167, taken from Dr. Black's book on Operative Dentistry, gives the results of his experiments, being corrected from the table as published in the *Dental Cosmos* for 1896.

The subject at present is not advanced far enough to dogmatize, as many amalgams which yield perfect results on being tested for physical properties out of the mouth, when inserted by the operator and seen a few years afterwards, look entirely different amalgams. Many amalgams containing both gold and platinum combined with silver, tin, and copper, are to be found doing excellent service in the mouth.

The following table, taken from the text-book written by the late Professor Charles J. Essig and Professor Augustus Koenig, gives a few typical examples of the composition of several of the best-known amalgams:

Name of Alloy.	Tin.	Silver.	Gold.	Platinum.	Copper.	Zinc.
Flagg's contour alloy	37·00	58·00	5·00	—	—	—
Flagg's submarine alloy	35·00	60·00	—	—	5	—
Flagg's facing alloy	35·00	37·00	5·00	—	—	3
Fletcher's platinum and gold alloy ..	50·35	43·35	3·35	1·30	1·65	—
Standard dental alloy (Eckfeldt)	40·60	52·00	4·40	—	3·00	—
Standard amalgam (Davis and Co.)	55·45	44·60	—	—	—	—
Sibley's gold and platinum alloy	54·65	43·15	0·20	20·00	—	—

Ageing of Alloys.—It has long been known that amalgams which have been prepared for some months exhibit properties not present in amalgams freshly pre-

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* Fletcher, "Dental Metallurgy," p. 39.

EXHIBIT OF MODIFIED SILVER-TIN ALLOYS.

Formula.	Silver.	Tin.	How Prepared.	Percentage of Mercury.	Shrinkage.	Expansion.	Flow.	Crushing Stress.
Modifying Metals.								
None	65·00	35·00	Fresh-cut	52·33	0	1	3·67	290
None	65·00	35·00	Annealed	33·00	10	0	5·00	335
None	66·75	33·25	Fresh-cut	51·52	0	4	3·35	329
None	66·75	33·25	Annealed	33·53	7	0	5·06	380
Gold 5	61·75	33·25	Fresh-cut	47·56	0	1	4·62	330
Gold 5	61·75	33·25	Annealed	30·35	7	0	6·07	395
Platinum 5	61·75	33·25	Fresh-cut	51·87	0	9	9·68	200–273
Platinum 5	61·75	33·25	Annealed	37·33	7	0	8·20	250–352
Copper 5	61·75	33·25	Fresh-cut	53·65	0	23	2·38	300–343
Copper 5	61·75	33·25	Annealed	35·60	5	0	3·50	416–450
Zinc 5	61·75	33·25	Fresh-cut	56·65	0	68	1·83	200–290
Zinc 5	61·75	33·25	Annealed	40·65	0	9	2·07	250–345
Bismuth 5	61·75	33·25	Fresh-cut	46·26	0	0	4·78	250–288
Bismuth 5	61·75	33·25	Annealed	23·67	6	0	5·58	308
Cadmium 5	61·75	33·25	Fresh-cut	57·57	0	100	6·40	225
Cadmium 5	61·75	33·25	Annealed	47·25	0	5	3·54	290
Lead 5	61·75	33·25	Fresh-cut	44·17	0	1	4·88	290
Lead 5	61·75	33·25	Annealed	32·76	10	0	7·18	276
Aluminium 5	61·75	33·25	Fresh-cut	65·00	0	445	—	—
Aluminium 1	64·50	34·50	Fresh-cut	46·98	0	166	12·60	198
Aluminium 1	64·50	34·50	Annealed	38·26	0	48	17·90	213

pared and inserted. An amalgam not freshly prepared is found to require less amalgam to render it plastic, is slower in setting, and frequently exhibits marked contraction on setting. This condition of the amalgam is referred to as the "ageing" of the alloy. It is not known definitely what changes do occur in the alloy, as the chemical composition remains similar, and if kept out of contact with air, as most amalgams are, there are no evidences of oxidation. Dr. Black has attempted to show how little importance need be attached to this process of ageing, as it has long been held to be a condition of the alloy much to be desired, and the manufacturers adopt, or did adopt, means to produce the change artificially. These may be summarized as follows:*

1. Immersing the cut alloy in boiling water, either enclosed in sealed tubes or exposed to the water.
2. By passing pure hydrogen, nitrogen, or oxygen gas, into a tube containing a cut alloy.
3. By cutting the alloy at a speed sufficient to generate heat in the process.
4. By exposing the cut alloy to the sun and shaking frequently.

It will be seen that none of these means incur a chemical change in the composition of the alloy, but all efforts hitherto to produce ageing by means of cold water or ice have failed. Whether it is of advantage to produce these changes or not is open to much speculation, as the subject of the behaviour of alloys and amalgams, and the changes occurring even after they have been formed for several years, is open for much investigation. It is held by many authorities on the subject that amalgams are improved in edge strength if annealed after being cut. This is a perfectly reasonable hypothesis if it is remembered that during the casting process many of the metals may have their crystalline formation modified, and if cut or filed rapidly this change may be even aggravated. Microscopical exam-

* Dr. Black's "Operative Dentistry," vol. ii., p. 309.

ination of rolled gold-foils shows that intelligent annealings of the metal produce a relief of the strain on the molecular structure, and the crystals after annealing resume their normal shapes. The method of bringing the metals together also plays an important part in the behaviour of amalgams, as the more perfectly they are intermixed, the better do the separate metals exercise their different effects. Granulating the alloys frequently before finally casting into ingots, by pouring them when molten into water ; preventing overheating during the process of fusion ; preventing oxidation of the metals by excluding air during the process of fusion by a thick covering of charcoal, or in an enclosed crucible in an atmosphere of hydrogen ; the rate and manner in which the alloy is reduced to powder, generating of heat being avoided ; absolute purity of the metals employed—these are the chief considerations to be noted, although it has been found that the production of alloys in large quantities entails a testing of each separate melting for the physical properties, and to insure that the metals are thoroughly intermixed. An unequal distribution of the component metals in an alloy produces wide variations in the physical properties, and in many alloys, where metals are employed which exhibit but slight affinity for each other, the tendency is for these metals to separate when on the point of cooling.

To Test for Gold in Alloys for Fillings.—The presence of gold in an alloy can be readily detected by placing a small quantity of the alloy in a test-tube, and adding some water. Then add strong nitric acid, and heat until the red nitrous fumes cease. Add more water, and allow to settle. In alloys containing gold the residue is dark purple in colour, being the purple of Cassius.

The Insertion of Amalgam Fillings—Amalgamating the Alloy.—It is generally agreed that all alloys should be amalgamated with definite proportions of mercury, which proportions may either be fixed by the operator from his observations of the behaviour of the amalgam, or by the manufacturer from examination of the physical properties. Many alloys require varying proportions of mercury, there being many causes which may give rise to divergences in the physical properties. The chief are—

(*a*) The method of preparation, whether in a closed electric crucible in an atmosphere of hydrogen, as advocated by Dr. Black, or in the ordinary crucible under a layer of charcoal or borax, etc.

(*b*) The method of reducing to a condition of powder, shavings, or bur cuttings, ready for mixing with mercury.

(*c*) The method employed to anneal or age the alloy.

All these, even in separate preparations of the same alloy, have a distinct effect on the behaviour of the alloy when amalgamated. Where definite proportions by weight are employed, many of the alloy manufacturers provide balances to give correct proportions of alloy and mercury. Many operators still depend upon the behaviour of the amalgam in the hand, mortar, or mixing-glass, to guide them. With many, the rule is to add the mercury drop by drop, and thoroughly amalgamate the alloy until the amalgam ceases to crumble before the pestle, or ceases to break into powder if mixed in a tube by shaking. It is then placed in the palm of one hand, and worked with the fingers of the other hand until it becomes plastic enough to give an impression of the skin of the fingers if pressed tightly between forefinger and thumb. The heat of the hand increases plasticity, and the use of heated instruments during insertion increases this still further; but provided excess of mercury has not been present in the mixing, heated instruments serve no good purpose. Excess of mercury should never be expressed from the amalgam, but fresh alloy, rather, added to bring the proportions to the right relationship. The mercury, if expressed, carries off most of the gold and silver present, thus altering the composition of the amalgam, and causing it to contract ; whereas in correct proportions it would probably expand. If amalgams be inserted too soft, having excess of mercury, contraction, lack of edge strength, and greater destruction to adjacent gold fillings, crowns, or dentures, ensue.

Inserting the Amalgam in the Cavity.—This is generally done by breaking the amalgam into small pieces, and carrying it to the place with a suitable carrier. Then with a ball, or round-ended burnisher, or flat-ended plugger, pressure is brought to bear either with a straight push or by giving the instrument a rotary movement. Many advocate burnishing from the cavity wall towards the free margin, or, as in the simple cavities, carrying the burnishing stroke from the centre to the margin. As the building and contouring of the amalgam proceed, the hand burnisher may be supplanted by a smooth-faced plugger, and the amalgam condensed by malleting. The important features are to condense the amalgam as perfectly as possible, adding the amalgam in small pieces and bringing it into perfect contact with the cavity walls, and never to carry the condensing to the point when the amalgam fractures. Such an accident frequently leads to improper cohesion in the body of the filling, which is changed in shape when subjected to the strain of mastication. Dr. Ottelengui advocates the use of several layers of thin gold-foil burnished on the surface of the amalgam, the contouring of the amalgam being carried to almost completion. The gold-foil absorbs some of the mercury, and by burnishing is incorporated in the filling. He holds that the gold increases the strength of the filling, improves the colour, and enables the burnishing to be completed at one sitting.

It is becoming a general practice to give the cavities for all metal fillings and inlays a protecting coating of oxyphosphate cement, as this protects the pulp from the thermal conductivity of the amalgam, and also to a great extent, from recurrent decay caused by even slight change in shape, chipping, or fracturing of the filling. The cement, by adhering closely to the cavity walls, makes it water-tight.

METHODS OF TESTING AMALGAMS FOR THEIR PHYSICAL PROPERTIES.—It has long been known that amalgam fillings are subject to change of shape, caused either by expansion or contraction of the mass after setting. Many of the pure silver amalgams expand excessively, causing fracture of the tooth walls ; while many of the modern amalgams have been demonstrated to possess the same undesirable property. Amalgams containing excess of tin and zinc exhibit the other extreme, contracting to a marked extent. In many amalgam fillings these changes do not occur until some months, or even years, have elapsed from the time of insertion. For an amalgam filling to fulfil its proper function, it should exhibit neither expansion nor contraction. It has never been demonstrated that human dentine can be made to expand, carrying with it its outer coating of enamel, with advantage to its function ; and if undue strain be exerted upon the dentine from within, the tendency is for it to yield before the pressure, exhibiting fissures or cracks on the thinner parts of the cavity walls, which provide new openings for the bacteria of caries to establish themselves. In small, simple cavities it is seen that where the cavity walls are strong, and do not yield to the pressure, the amalgam exhibits expansion entirely in an upward direction, the term " spheroiding " having been applied to this change of shape. Carefully examined under strong glasses, such fillings are seen to have increased perhaps markedly in bulk in the upward direction, as is emphasized by their impinging on the bite after having been ground and polished quite clear on a previous occasion, and that the walls of the cavity are no longer protected against caries, the amalgam having drawn away from them. This is further proved by the darkening of the tooth structure by caries, and the products of oxidation of the metals, kept immersed in a moist and warm surrounding. Expansion, to be of service, must therefore be shown to set in, not in the line of least resistance, but in all directions. Contraction in mass of an amalgam filling should condemn it for use in the mouth. Many amalgam fillings, where subjected to the crushing strain of mastication, are altered in shape, and disclose wide margins for the ingress of food débris and bacteria.

At the present time most amalgams are subjected to tests for their physical properties, to determine especially whether they expand or contract, the number of pounds pressure producing a change of shape, and their tendency towards oxidation. The various instruments employed may be grouped as possessing several essentials in common. The micrometer as adopted by Dr. Thomas B. Hitchock, and that by Dr. Black, have been latterly employed by most of the firms preparing dental amalgams.

To Test Amalgams for Expansion or Contraction. — The amalgam, being carefully mixed, is packed in a small circular steel tube, engine-turned in the centre for accuracy, and having a notch cut to prevent the amalgam being forced out by any change of shape. The amalgam is allowed to set, and then polished on both exposed surfaces to meet the exact level of the surface of the tube. It is placed again in the tube into a section of the micrometer, where it rests on its side in an accurately fitting bed. Pointers connected with the instrument are brought to touch the centre of the amalgam on either side, and any change of shape is recorded on a dial scaled to $\frac{1}{10000}$ of an inch. By this means the changes occurring can be recorded in definite figures. Again a tube containing an amalgam is taken, and the surface of the tube and amalgam carefully polished, and by the use of a binocular microscope any change of shape may be observed. Or the amalgam may be packed into a slide made in two equal sections and secured in place. After the amalgam has set, the two halves of the slide are separated, and the amalgam allowed a few days to still further harden, and by replacing it in the slide any change of shape may be observed by the microscope.

To Test Edge Strength.—In these experiments the amalgam is withdrawn from the tube, and placed securely in a suitable receptacle ; pressure is brought to bear on its surface, the yield, if any, being recorded on a dial accurately scaled to pounds pressure. In ordinary testing the alloy is placed on the bed plate of a crushing machine, and the point at which the alloy yields is recorded, the pressure being increased until this point has been reached. For dental amalgams, the pressure is seldom carried beyond 80 pounds, this being regarded as the maximum pressure exerted on an amalgam filling during mastication.

The use of the microscope for the examination of alloy and amalgams affords a valuable means of observing the changes occurring, and also, by polishing the surface and washing with suitable reagents, the distribution of the several metals in the amalgam may be observed and photographed.

FLOW OF AMALGAMS. — Amalgams possess this property in some instances to a remarkable extent. The flow is produced by the intermittent pressure exerted upon the amalgam, usually during mastication, and in cases where the patient grinds the teeth together during sleep. In compound cavities this flow is in the line of least resistance—*i.e.*, in the direction of the absent wall or walls—and, if marked, the filling ceases to protect the cavity against moisture and caries. The test for the flow of amalgams consists in fixing a disc or ingot of amalgam in the receptacle in the micrometer similar to that used in testing for edge strength, and bringing a pointer to bear to its surface ; continuous or intermittent pressure is applied for several days. The yield or change in shape is recorded on the dial as in the previous test for edge strength. Needless to say, amalgams exhibiting this property are discarded.

CHAPTER XVIII

THE BEHAVIOUR OF METALS IN THE MOUTH

The metals used for filling materials are few in number, gold and tin being used pure, while gold, platinum, silver, copper, tin, and zinc, are constituents of alloys for amalgams ; for base-plates, gold, platinum, silver, and copper, these being either as reduced carats or alloys of gold, or the alloy of platinum and silver known as dental alloy. Iridium is used as bars in bridge work, and alloyed with platinum for pins for porcelain teeth. Aluminium is used pure as swaged in sheet form or cast ; as the alloys of aluminium and silver, etc., and as the alloy of copper and aluminium, known as aluminium bronze or "Victoria metal." Tin is used alloyed with silver and gold in the cheoplastic process. For correcting cases of malocclusion, German silver (the alloy of nickel, copper, and zinc), steel piano wire, and iron or steel, in the various appliances, as nuts, springs, etc. With the exception of the metals used as temporary appliances, such as are employed in orthodontia, or in cases of fracture of the inferior maxilla, the others are applied with the view that they are permanent and of unalterable characters.

The question of voltaic action has been dealt with under the physical properties of metals, but the observed effects resulting from this, and other known and unknown causes upon metals, present some features of peculiar interest. Pure gold, for instance, when inserted as a filling in some mouths, remains clear in colour and smooth on the surface for indefinite periods ; while in others the same form of gold, inserted with equal care and by the same operator, rapidly discolours, and in time discloses visible imperfections of the surface, especially in the interstitial spaces and towards the cervices. It has been noticed in the latter cases that amalgam fillings become pitted on the surface, and show markings not to be accounted for by spheroiding, but more closely resembling a washing out, as is to be observed in cement fillings. If the amalgam fillings are removed, and porcelain inlays, gold fillings, or gold inlays, substituted, the discoloration ceases. It is also observed that in gold crowns in close proximity to amalgam fillings (and this need not imply that they be in adjacent or opposite teeth) the same action results—*i.e.*, discoloration of the crown, roughening of the surface, and deterioration generally of crown and filling.

Dentures of gold, dental alloy, vulcanite dentures with gold clasps, bridges, etc., all produce similar effects, besides the extreme discomfort produced by voltaic action already mentioned. Bars of German silver used as arches for cases of malocclusion, dummy props in bridges and dentures, strengthening wires in dentures, etc., disclose on examination marked changes after a few months' exposure to the salivary fluids. The German silver becomes pitted and corroded, and if it has been sealed in position, especially as tubes or bars, may snap through, even when orginally protected by a plating of gold. These changes are more rapid in some of the inferior grades of German silver containing iron ; and in the alloys recently introduced as crown posts, base-plates, pins for teeth, etc., many of which contain iron, nickel, copper, zinc, lead, tungsten, etc.

Changes of a similar character—*i.e.*, corrosion, and pitting of the surface—are to be observed in alloys of gold and platinum, especially where zinc is one of the metals added to reduce the carat and melting-point. From observation, it has been found that the discoloration of gold fillings and gold inlays, in the great majority of cases, is not due to the formation of a film of auric sulphide caused by the presence of sulphuretted hydrogen in the saliva, but is a coating of copper deposited from amalgam fillings by electro-chemical action, this action always being more pronounced where electro-positive and electro-negative metals are brought together. Mr. Clarence J. Grieves, in his paper published in the *Dental Cosmos* for September, 1909, expresses this as follows : " Metals violently electro-positive and negative to each other should not be used in alloy or apposition in the human mouth, with the saliva as an electrolyte—as, for instance, gold and zinc, copper and zinc, etc." That such action does occur in the mouth is beyond dispute, and in a case reported in the journal *Electricity*, where a base-plate of metal had teeth backed and soldered to position by two dissimilar metals, the patient complained of intense pain in the tongue and surrounding tissues. Tests made with a galvanometer recorded that the voltaic action set up by these metals, in conjunction with natural saliva, was sufficient to account for the discomfort.

Reference to the table given in the Appendix detailing the comparative conducting powers of the metals will show the wide difference which exists between many of the metals commonly brought together as alloys.

The use of zinc as a substitute for platinum in most of the cheap amalgams, to reduce the quantity of mercury required, and also to hasten the setting of the amalgam, has been carried to excess. These amalgams, being highly electro-positive in presence of such metals as pure gold, or amalgams containing gold, platinum, silver, copper, and tin, induce in these chemico-electric destruction, the zinc amalgam itself disclosing excessive pitting of the surface and diminution in bulk. Observations teach that, where zinc is added, 1 to 2 per cent. should never be exceeded, as fastness in setting and whiteness in colour of the amalgam can be obtained without adding zinc to excess. The following list will give a comparative idea of the relative electrical positions of the metals most commonly in use:

Zinc.
Iron.
Aluminium.
Lead.
Tin.
Bismuth.
Nickel.
Copper.
Mercury.
Platinum.
Gold.
Antimony.

Each metal is usually positive to all those below it, and negative to those above, so that the terms "electro-positive" and "electro-negative" are comparative terms. Base and alkali metals are usually regarded as positive, and metalloids as negative.

Zinc is usually added to improve the flow of gold solders and base-plate metal, and in several instances is found in platinized golds as used for bars, clasps, etc. In every instance where the metal is added in appreciable proportions—say 5 per cent. and over—the pitting, grooving, and even disintegration, of the surface of the gold or alloy is observed. Aluminium pure, and aluminium bronze, gold, dental alloy, alloys of platinum and iridium, besides the alloys and amalgams already mentioned, all seem to be affected in varying degrees by what may be regarded as electrolysis in the mouth, the saliva charged with the acids formed by the decomposition of food left between the teeth acting as the electrolyte.

The subject is one which is open for much investigation, and this brief note is inserted to draw the student's attention to what, to the young operator, appears a mystery, and often leads to great disappointments. So far as research work has been undertaken at present, it may be regarded as accepted that voltaic action does occur in the mouth, and that, while a lining of oxysulphate or oxyphosphate of zinc may relieve or remove the discomfort from the pulp of the tooth filled with a highly positive amalgam, the voltaic action upon other teeth, soft tissues, or metals in the mouth, is not arrested. To sum up, then, we may say that the three chief causes of such voltaic action are—

1. A hyperacid condition of the saliva. In such cases erosion may not be present, but the mere contact of a wet spatula on the surface of an amalgam or gold filling causes the tooth pulp to respond.

2. Gold and amalgam fillings occurring in close proximity to each other, either as approximal fillings or articulating with each other. Very pronounced action is felt frequently when a gold crown is in contact with, or articulating with, an amalgam filling. In such cases the crown is attacked, not merely by absorption of mercury and discoloration, but by an action resembling erosion in many points.

3. A denture or bridge of a different composition from the fillings, crowns, etc., which it may come in contact with. As the subject is at present, it may be inferred that better results would be obtained if metals as uniform in their relative electrical positions as possible were inserted in the mouths of patients. It has already been pointed out that amalgams yielding satisfactory results, when tested for their physical properties outside the mouth, behave after insertion in a manner quite the reverse of what might be expected, spheroiding, showing lack of edge strength, and failing to protect the cavity against the attacks of bacteria, when in use for several years. Further research work, therefore, is necessary along this line, to determine exactly the causes for these changes, and how best to preserve our conservative work against such changes.

CHAPTER XIX

CASTING OF METALS

For many purposes metals are cast into shapes required instead of being cut, swaged, or forged, from the solid piece, either as sheet, bar, or ingot. The casting of most metals facilitates and cheapens the production of articles complicated in shape, great in weight, and made of metals or alloys offering great resistance to cutting tools, and low in malleability. Among the latter class may be mentioned the casting of machine tools composed of tungsten-steel alloys, which alloy is extremely difficult to cut, and which is employed largely for cutting all forms of mild and hard steel and other alloys. Of recent years the casting processes have been introduced into dentistry for the production of metal dentures, bridges and inlays, impression trays, etc. For dentures the processes may be divided roughly into two divisions.

CASTING BY GRAVITATION.—In this process the weight of the metal carries it through a gate or sprue vent leading to a mould of the denture. The metal is made thoroughly liquid, and the flask containing the inverted mould brought to a brisk heat, when the metal is poured to fill up the mould, displacing the air, and emerging from a vent established in the mould and flask for the purpose. (See Tin.)

CASTING UNDER PRESSURE.—The metal is melted in a hollow crucible shape, formed upon the upper surface of the mould investment, and forced through the gate or sprue vent communicating with the mould. To effect this, several methods are in use. Air pressure developed in an air-pressure cylinder may be brought to bear on the molten metal, which, being enclosed at the same moment as the air pressure is applied, receives the full force of the pressure. Steam pressure also has its advocates. In this process a cap, made to fit securely over the ring or flask containing the invested mould, is filled with damp asbestos, or fitted with a moistened amianthus washer. When the metal is liquid and the investment hot, the cap is closed tightly over the investment, the steam generated forcing the metal down the gate into the mould.

CASTING BY VACUUM.—Instead of pressure from above, the use of the vacuum has been applied with some success. The ring containing the investment and mould is machined to accurately fit a bed plate pierced in its centre, and communicating with the vacuum chamber and pump. The vacuum having been established generally to about 20 pounds, by pumping the air from the chamber, the ring and investment are brought to a red heat. The metal is melted, and made thoroughly liquid either in a hollow cut in the surface of the investment or in a separate crucible ; the key of the pump is then released, and the pull established by the vacuum draws the air from the investment and mould, causing the metal to run in and fill the vacuum thus established. Of the three classes mentioned, there are numerous modifications, but the principles governing these are as stated.

The casting of metals by gravitation is generally limited to those metals and alloys whose melting-points are moderately low.

The following are a few of the metals and alloys with which this process is employed :

Pure tin, as used in the cheoplastic process for cast lowers.

Bean's alloy, containing 95 parts tin, 5 parts silver.

Reese's alloy, containing 20 parts tin, 2 parts silver, 1 part gold.

Kingsbury's alloy, containing 16 parts tin, 1 part antimony.

Kingsley's alloy, containing 16 parts tin, 1 part bismuth.

Carrol's alloy, containing aluminium, tin, copper, and silver.

Pressure casting is used with pure aluminium and several aluminium alloys which are especially employed for upper dentures. Several of these alloys, such as Brophy's metal and Aerdentalloy, are proprietary, and their composition unknown.

Carrol's base No. 1 contains—

Aluminium	98 per cent.
Platinum	2 per cent.*
Silver	
Copper	

Many of the alloys contain aluminium with small proportions of silver, or silver and tin. The addition of silver renders the alloy less liable to attack from alkaline salivas, salt, etc., while the percentage of silver is kept low to avoid expansion and excessive oxidation. For many classes of cast work the various gold alloys are employed. For dentures, 20 and 18 carat alloys are most frequently employed, the percentage of copper being partly displaced by silver and zinc to increase fluidity and avoid contraction. Gold of 17 carat, reduced from Australian sovereigns, casts well, the alloy being extremely fluid and strong. The colour is lighter than that of Californian or South African golds. Aluminium bronze is employed for less expensive work. This alloy has an extremely varied range of colours, and can be obtained closely approximating 18 and 20 carat gold, and also the platinized gold alloys. These colours are generally produced by varying the proportions of copper. The alloy containing 95 parts copper and 5 parts aluminium is much redder in colour than that containing from 8 to 10 parts aluminium. The alloy requires great heat to render it fluid, and, when molten, the formation of oxides on its surface frequently interferes with the flow of the metal in the mould.

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* Turner's "Prosthetic Dentistry," p. 667.

Inlays are generally cast of 22 carat gold, seldom being lower than 20 carat. Some advocate the use of pure gold plus a trace of platinum and copper to increase the edge strength. The inlays of 22 carats made from crown gold formulæ give good results, especially where the gold is carried to restore a grinding surface or cutting edge, the metal showing little tendency to chip or change in shape even under severe use. The carrying of high-carat gold to feather edges on cutting surfaces should be carefully avoided, as the metal gives good results provided it is borne in mind that it does not possess greater edge strength, when cast, than first-grade amalgams. The alloy recommended by Dr. Black, containing 73 to 75 parts silver to 25 to 27 parts tin, flows well, retains good colour, and for large restorations or plastic work, or for inlays for hospital work, can be used with advantage.

The whole subject of casting under pressure is, at the time of writing, entirely in the developmental stage, but, used with discretion, the process can be employed with advantage for many purposes. It must be remembered, however, that cast metals do not possess the same strength or tenacity as rolled metals. The lack of tenacity and elasticity is at once noticed if a clasp turned up from plate metal is compared with one cast under pressure; the pressure casting, if bent several times by way of adjustment, fractures. If it were possible to hammer the castings, the alloy would be much improved in strength and elasticity; but where clasps, bars, or extensions, requiring the full extent of the elasticity of the alloy are necessary, they are best prepared from rolled or drawn metal, and soldered to the rest of the casting. For technique of the processes, see text-books on Prosthetic Dentistry.

CHAPTER XX

HARDENING, ANNEALING, AND TEMPERING, OF METALS

THE subject has already been briefly referred to in dealing with steel and gold.

HARDENING.—There seems to exist a certain amount of confusion regarding the application of the terms hardening, annealing, and tempering. The term *hardening* is more properly confined to the change effected in a metal by sudden cooling after it has been raised to a bright red heat or higher temperature. With steel, for instance, the sudden cooling of a finely-constructed scaler or chisel will cause the instrument to snap off short if strain be applied; whereas, on undergoing tempering, the metal is found to possess greater elasticity and strength than before, and yet retains the fine cutting edge it may have received, even when employed to cut such hard substances as salivary calculi and enamel. In the case of gold-hardening, the metal can be affected by simply rolling or hammering. Advantage is taken of this in the manufacture of finger rings made to receive precious stones, where elegance and lightness are desired. The gold is hammered after being rolled, this bringing the molecules of the gold into more intimate contact, and to a greater state of tension, with the result that the gold is reduced in bulk but possesses greater rigidity and strength. The same change occurs in striking up a gold plate, the hammering with the horn mallet gradually producing a hardening effect on the metal ; and if the hammering be continued beyond this point, the metal fractures, not because it has been stretched to its limit of tenuity, but because its limit of compression has been exceeded.

ANNEALING.—The term should be confined to the relief of strain in metals produced by hammering, rolling, drawing, or by rapid cooling from a high temperature. The effect of the process of annealing is very marked in the case of gold plate struck up for a base-plate, already referred to. Once hardening has set in, which can be noted by the harsher ring produced by the stroke of the mallet, the metal is seen to yield less in response to the stroke. If at this stage, or preferably before, the metal is raised to a dull red heat and allowed to cool in the air, it is found to be comparatively soft and pliable, and shows little tendency to rupture if it receives moderate care. The lower the carat of gold, the more frequent is annealing necessary. Dental alloy, especially the grade containing 25 per cent. platinum, should usually be raised to a bright red, and kept at that heat for a few seconds. Alloys containing platinum generally require a higher temperature in annealing, and the alloy of gold and platinum as foil used for fused inlay matrices is much softer to work if raised to an almost white heat for one or two seconds. Examinations of micro-sections of gold before and after annealing seem to encourage the belief that in the hard state the molecular structure is drawn and attenuated, whereas after annealing the structure is seen to have recovered to the normal, by the molecules having contracted to their former proportions. The effects of annealing as seen on micro-section of alloys, such as steel, bronze, etc., are best studied from general text-books. It may be briefly stated, however, as regards steel (the alloy of iron and carbon, as it is now regarded), that, compared with the hard state, annealing seems to disseminate the carbon particles more uniformly through the iron, the distribution of the carbon seemingly playing a most important part in the physical properties of steel.

Alloys as used for filling purposes for dental amalgams are generally subjected to a process of annealing after being cut to powder or filed to particles ready for use. Many authorities on the subject differ as to what temperature the alloy should be heated, and what length of time should be spent in the process. It is generally held that the effect of annealing is to lessen contraction in the finished fillings, and to increase the edge strength, resistance to attrition, etc. In annealing pure gold. as for filling purposes, the metal is best kept from contact with the naked flame of the spirit-lamp. This is especially applicable to cylinders, matt and fine foils. The electric annealers, the sheets of mica supplied with small portable stands, give excellent results, provided prolonged or over-heating is avoided. The practice common among many of the profession, of heating the gold at the naked flame, using the plugger point as the carrier, and using ordinary industrial methylated spirits, should be discouraged, as the other practice yields more satisfactory results. (See Gold.)

TEMPERING.—With the exception of steel, there are no alloys employed in dental metallurgy requiring tempering, and the subject has been dealt with under Steel. It is thought that, if steel be brought to a certain temperature, and cooled either in fat, oil, or water, the particles of carbon, etc., disseminated through the iron are then set in whatever position or state they may have been when the metal was strongly heated. Heat when applied to steel and the alloys of steel causes a rearrangement of the molecular structure. The extent to which this rearrangement takes place depends upon the temperature to which it is heated, and also the length of time the temperature is maintained; and if the tempering be effected at the temperatures as given already, or according to the colour attained by the steel, it will be noted how vastly different are the effects produced by even a slight difference of temperature (see p. 32).

[illegible]

CHAPTER XXI

PYROMETRY

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WHEN the fusing-points of the different metals are under study, it will be seen that at times there are wide variations in the figures given by the different writers, even for the same metal. This in the past has been due to the figures being taken of the melting-points of impure metals, and also to the absence of any reliable method of determining high temperatures.

At the present time the methods available for registering temperatures, though they may vary widely in principle, are generally sufficiently accurate for the figures given to be accepted, the difference between authorities generally being in the expression of a decimal fraction. As early as the eighth century we find that Geber* held the view " that heat could not be measured, and that consequently great difficulty attended operations requiring heat " ; and the same view seems to have held good for another ten centuries. Wedgwood, of Wedgwood ware fame, saw that it would be much to his advantage, and the bettering of his products, if his workmen had some reliable means afforded them of keeping a check on the heat of the furnaces and ovens, and from his experiments gradually developed the modern system of pyrometry. He clearly saw the importance of being able to distinguish the gradations between the bright red heat and the blazing white heat that some of his ware had to be raised to. His early attempts were confined to watching the contraction of various clays when strongly heated, marking their change of shape, etc., until he had reached a practicable working basis. At present there are innumerable devices employed to register temperatures.

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* Sir W. Roberts-Austin, " Introduction to Metallurgy."

The thermometer is too well understood to require more than mention, but very high temperatures cannot be registered by its use. Pyrometers, on the other hand, are intended to register temperatures beyond those possible by the ordinary thermometer, and vary in construction according to the various purposes to which they are applied.

For use with electric furnaces for fusing dental porcelains, the pyrometer generally used is the thermo-couple. The use of this instrument depends upon the fact that, if two dissimilar metals joined together at one end are heated, a current of electricity is produced, and that this current is nearly proportional to the temperature, and can be measured by the deflections of a dead-beat galvanometer. This galvanometer may be of the mirror form, or may be provided with a dial and pointer. The scale on this dial is calibrated from known and definite melting-points.

The use of the thermo-junction appears to have been first suggested by Becquerel in 1826, and was adopted by Pouillet some ten years later. At first the metals forming the thermo-junction were badly chosen, and at a later date Professor Le Chatelier advocated the use of platinum in conjunction with platinum alloyed with 10 per cent. rhodium. Barns, on the other hand alloyed the platinum with iridium, as suggested by Tait, obtaining good results even at very high temperatures.

DENTAL PYROMETERS.—These instruments are generally of the thermo-junction type, the variations being confined to the manner of attaching them to the electric furnace. Some have the thermo-junction loose, to be laid on the floor of the furnace, while others have it embedded in the fireclay walls of the furnace. Both of these types may be held open to objection. The loose form is likely to record the temperature of the furnace nearest the door, as the tray holding the porcelain to be fused will occupy the greater part of the area at the back, where the heat is generally greatest. When the junction is embedded, it is less accessible in the case of repairs being necessary, either to the junction, the electric wiring of the furnace, or to the muffle walls.

The thermo-junction consists of two wires, one of which is of platinum, the other an alloy of platinum with 10 per cent. of rhodium or iridium. These are soldered together only at the end in contact with the heat, and connected with a dead-beat galvanometer of about 200 ohms resistance. The temperature is recorded on a scaled dial on the galvanometer, which may be of the suspended type, quite separate from the electric furnace; may be built in on the same base as the furnace; or may be loose to hang to a wall or bracket, etc.

These pyrometers are intended to register temperatures up to 4,000° F., such as are required for fusing high-grade porcelains. In using pyrometers in fusing porcelain, as in inlay and continuous gum-work, where porcelains of different fusing-points are employed, and where in the preliminary firings it is only essential to raise the heat sufficiently high to give the porcelain a biscuit glaze, and cause it to reach its ultimate contraction, exact temperatures are absolutely essential to produce good results. It is found in practice that pyrometers are more accurate if the current of electricity is admitted gradually to increase the temperature slowly, and that, once the desired temperature is reached, the furnace should be allowed to cool before reheating. The practice of allowing the current to remain on until the second or subsequent firings have been completed interferes with the electrical disturbance set up in the thermo-junction, and the readings on the dial are less reliable.

When the temperatures required are not so high, the thermo-junction varies in composition. Thus, where 1,800° to 2,090° F. is the highest desired, the thermo-junction may be nickel and steel, as made by Messrs. Crompton and Co. In this pyrometer, a nickel rod runs down the centre of a steel tube without touching it, except at the extreme end, where the two metals are welded together. The couple is in connection with a recording galvanometer, as in the case of those pyrometers described. There are many modifications of electrical pyrometer, which are used chiefly in iron and steel works. In the Siemens electrical pyrometer acidulated water is decomposed both by the current from the junction and from the resistance coil, the difference in quantity decomposed between the junction and the resistance affording a means of registering temperatures.

Sir W. Roberts-Austin produced a pyrometer by means of which continuous records of temperatures can be obtained by means of sensitized paper on a revolving drum, much in the same way as differences of temperatures and air pressures are recorded by self-recording aneroid barometers, etc.

LE CRON'S PYROMETER PELLETS.—For dental purposes where occasional firings, as with porcelain, are undertaken, the series of alloys introduced by Dr. Le Cron in the form of rounded beads is extremely useful. They can be obtained covering a wide range of temperatures (2,000° to 3,000° F.), to suit the fusing-points of the best-grade porcelains.

Method of Use. — A bead of the alloy is chosen whose melting-point coincides with the fusing-point of the porcelain to be used. It is placed in the circular opening in the top of a small open-sided crucible stand made for the purpose. This is then introduced into the furnace with the inlay or piece of continuous gum-work. When the temperature reaches the melting-point of the alloy, the bead becomes liquid, and drops through into the concave base of the crucible or stand, and the porcelain is found to have fused.

APPENDIX

TABLE OF ALLOYS.

Aich's Metal	Copper 60 to 70, zinc 38·2, iron 1·8, per cent.
Aluminium Bronze (1)	Copper 95, aluminium 5, per cent.
Aluminium Bronze (2)	Copper 90, aluminium 10, per cent.
Aluminium Gold	Gold 78·48, aluminium 21·52, per cent.
Aluminium Silver	Copper 70, nickel 23, aluminium 7, parts.
Aluminium Tin	Aluminium 100, tin 10, parts.
Arguzoid	Copper 56, nickel 13·5, zinc 23, lead 3·5, tin 4, per cent.
Babbit Metal (1)	Tin 66, antimony 22·3, copper 11·1, per cent.
Babbit Metal (2)	Tin 24, antimony 8, copper 4, parts.
Haskell's	Tin 8, antimony 2, copper 1, parts.
Fletcher's	Tin 70·6, antimony 17·64, copper 11·76, per cent.
Bean's Alloy	Tin 95, silver 5, parts.
Bell Metal	Copper 80, tin 20, per cent.
Blue Gold	Iron 75, gold 25, per cent.
Brass	30 to 40 zinc, copper 60 to 70, per cent.
Sheet	Copper 70, zinc 30, per cent., and a trace of lead.
Casting	Copper 47, zinc 50, tin and lead, 3, per cent.
Britannia Metal (1)	Tin 42, antimony 3, copper 1, brass 1, parts.
Britannia Metal (2)	Tin 90·7, antimony 7·8, copper 1·5, parts.

Carrol's Alloy	Aluminium 98, platinum, silver, and copper 2, per cent.
Crown Gold	Gold 22 dwts., silver 18 grs., copper 1 dwt., platinum 6 grs.
Dental Alloy (1)	Silver 75, platinum 25, parts.
Dental Alloy (2)	3 to 10 grs. platinum per dwt. of silver.
Dorrance's Alloy	Copper 6, silver 2, zinc 4, parts.
Dutch Metal	Copper 84·6, zinc 15·6, per cent.
Electrum Metal	Copper 51·6, nickel 25·8, zinc 22·6, per cent.
Fusible Alloys:	
Brophy's	Bismuth 12, tin 10, lead 11, parts.
Crouse's	Bismuth 8, tin 5, lead 5, cadmium 1, parts.
Fusible (1)	Bismuth 3, tin 2, parts.
Fusible (2)	Bismuth 48, tin 26, lead 19, cadmium 13, parts.
Fusible (3)	Bismuth 4, tin 12, lead 15, parts.
Lichtenberg's	Bismuth 7, tin 7, lead 13, cadmium 2, parts.
Lipowitz's	Bismuth 15, tin 4, lead 8, cadmium 3, parts.
Molyneaux's	Bismuth 5, tin 2, lead 3, cadmium 2, parts.
Newton's	Bismuth 8, tin 3, lead 5, parts.
Rose's	Bismuth 8, tin 3, lead 8, parts.
Wood's	Bismuth 5, tin 2, lead 4, cadmium 2, parts.
German Silver:	Copper 5, nickel 2 to 3, zinc 3·5, parts.
German Silver as in Plate	Copper 5, nickel 2, zinc 3, parts.
German Silver Solder	Copper 50, nickel 20, zinc 30, parts.
Gold Alloys:	
22 Carat	Gold 22, silver 1, copper 1, parts. – 1,800°F.
21·6 Carat (1)	Gold 90, silver 5, copper 5, parts.
21·6 Carat (2)	Gold 50, silver 5, coin gold 45, parts.
20 Carat for Base-plates	Gold 20, silver 2, copper 2, dwts. 1,760°c
20 Carat Platinized (1)	Gold 20, silver 1, copper 2, platinum 1, dwts.

Gold Alloys—*continued:*	
20 Carat Platinized (2)	Coin gold 20 dwts.; silver 10, copper 8, platinum 10, grs.
18 Carat for Base-plates (1)	Gold 18, copper 4, silver 2, dwts. – 1,760° F.
18 Carat for Base-plates (2)	Gold 18, copper 3, silver 3, dwts.
18 Carat Platinized (1) ..	Gold 18, copper 1, silver 4, platinum 1, dwts.
18 Carat Platinized (2) ..	Gold 18, copper 3, silver 2, platinum 1, dwts.
17 Carat Platinized ..	Gold 17, copper 4, silver 2, platinum 1, dwts. 1,800° F.
16 Carat Platinized ..	Gold 24, copper 2, silver 1, platinum 1, dwts.
16 Carat for Base-plates (1)	Gold 16, copper 4, silver 4, dwts.
16 Carat for Base-plates (2)	Gold 11 dwts., copper 2 dwts. 6 grs., silver 4 dwts. 6 grs.
Gun Metal	Copper 90, tin 10, per cent.
Kingsbury's Alloy	Tin 16, antimony 1, parts.
Kingsley's Alloy	Tin 16, bismuth 1, parts.
✓ **Levol's Homogeneous Alloy** ..	718·93 parts silver per 1,000 parts copper.
Mannheim Gold	Copper 75, zinc 25, per cent.
Meter Metal	Tin and lead in equal parts, with a trace of antimony.
Mosaic Gold	Copper 50, zinc 50, per cent.
Muntz Metal	Copper 64, zinc 36, per cent.
Pewter Metal (1)	Antimony 15, lead 6, tin 79, per cent.
Pewter Metal (2)	Tin 12, antimony 3, parts.
Phosphur Bronze	Phosphorus 0·25 to 3, tin 5 to 15, per cent., and the remainder copper.
Pinchbeck's Alloy	Copper 90, zinc 10, per cent.
Platinum Solder	Gold 75, platinum 25, parts.
Platinoid (1)	Copper 60, zinc 24, nickel 14, tungsten 2, parts.
Platinoid (2)	Copper 60·50, nickel 15·97, zinc 23·00, lead 0·12, iron 0·35, cadmium 0·12, per cent.
Reese's Alloy	Tin 20, silver 5, parts. [illegible]
Steels:	
Aluminium Steel ..	Not more than 1 per cent. aluminium.
Chrome Steel	From 0·25 to 2 per cent. chromium.
Manganese Steel ..	From 6 to 14 per cent. manganese.

Steels—*continued*:		
Nickel Steel		From 2 to 4 per cent. nickel, and 0·2 to 0·3 per cent. carbon.
Silicon Steel		Similar to aluminium steel.
Tungsten Steel		2 to 7 per cent. tungsten added to 2 to 3 per cent. steel.
Solders:		
Aluminium Solders: —		Zn 8, Sn [illegible] Sb [illegible] oleic acid.
Aluminium Solder (1) . .		Aluminium 20, zinc 80, parts.
Aluminium Solder (2) . .		Aluminium 8, zinc 92, parts.
Common Solder		Copper 4, aluminium 6, zinc 90, parts.
Hard Solder	*For Aluminium Bronze*	Gold 88·8, silver 4·68, copper 6·44, per cent.
Medium Hard Solder		Gold 54·40, silver 27·00, copper 18·00, per cent.
Platinum - Aluminium Solder (Schlosser)		Gold 30, platinum 1, silver 20, aluminium 100, parts.
Gold-Aluminium Solder		Gold 50, silver 10, copper 10, aluminium 20, parts.
Hard Solder		Pure block tin from 90 to 98 parts, bismuth from 1 to 5 parts, aluminium from 1 to 5 parts.
Soft Solder (Frismuth) . .		Pure block tin 90 to 99, bismuth 1 to 10, parts.
Thowles's Solder . .		Tin 55, zinc 23, silver 5, aluminium 2, parts.
Solder for Trays, etc. (1)		Zinc 62·5, tin 25, lead 12·5, per cent.
Solder for Trays, etc. (2)		Cadmium 50, zinc 20, tin 30, parts.
✓ **Fine Solder**		1 part lead to 2 parts tin.
Gold Solders:		
✓22 Carat Solder		Pure gold 22, brass 2, grs.
20 Carat Solder, or No. 00 (1)		Pure gold 20, zinc 1½, silver solder 3, grs.
20 Carat Solder, or No. 00 (2)		Pure gold 5 dwts.; pure silver 12, copper 6, grs.
20 Carat Solder		Pure gold 20, Dorrance's alloy 4, dwts.
✓18 Carat Solder, or No. 1 (1)		Coin gold 30, pure silver 4, pure copper 1, brass 1, parts.
18 Carat Solder, or No. 1 (2)		Coin gold 19½, pure silver 2½, pure copper 1, brass 1, dwts.
16 Carat Solder, or No. 2 (1)		Pure gold 11 dwts., pure silver 3 dwts. 6 grs., pure copper 2 dwts. 6 grs.

Solders : Gold—*continued :*

16 Carat Solder, or No. 2 (2)	Pure gold 11 dwts. 12 grs., pure silver 3 dwts., pure copper 1 dwt. 12 grs., pure zinc 12 grs.
15 Carat Solder (Jeweller's) (1)	Pure gold 15, pure copper 5, pure silver 4, dwts.
15 Carat Solder (Jeweller's) (2)	Standard gold (22 carat) 16½, pure copper 3½, pure silver 4, dwts.
15 Carat Ordinary (1) ..	Pure gold 15, pure copper 4, pure silver 4, brass 1, dwts.
15 Carat Ordinary (2) ..	Standard gold 17, pure copper 4, pure silver 2, brass 1, dwts.
14 Carat Solder	Pure gold 14 dwts., pure silver 5 dwts., pure copper 3 dwts. 12 grs., pure zinc 1 dwt. 12 grs.
✓ 12 Carat, or No. 3 (1) ..	Pure gold 12, pure copper 6, pure silver 5, brass 1, dwts.
12 Carat, or No. 3 (2) ..	Standard gold 13, pure silver 6, pure copper 5, dwts.
Plumber's Solder	2 parts lead to 1 part tin.
Soft or Common Solder ..	50 parts lead and 50 parts tin.
Silver Solders :	
✓ No. 1	Silver 66, copper 30, zinc 10, parts.
✓ No. 2	Silver 6, copper 2, brass 1, parts.
✓ No. 3	Silver 4, brass 3, parts.
No. 4	Silver 20, brass 10, zinc 5, copper 1, parts.
No. 5	Silver 4, brass 2, zinc 1, parts.
No. 6	Coin silver 9, zinc 1, parts.
Speculum Metal	Tin 33, copper 67, parts.
Sterro metal	Copper 55 to 70, zinc 34 to 44, iron 1 to 2, tin 1 to 2, per cent.
Tiersagent	Aluminium 66·5, silver 33·5, per cent.
Tutenag	Copper 45·7, nickel 17·4, zinc 36·9, per cent.
✓ **Type Metal** (1)	Antimony 25, lead 75, parts.
✓ **Type Metal** (2)	Antimony 18, lead 70, tin 10, copper 2, parts.
✓ **Type Metal** (3)	Antimony 1, lead 8, tin 1, parts.
Von Eckhart Alloy	Copper 11·71, silver 3·53, platinum 2·40.

TABLE OF PHYSICAL CONSTANTS OF THE MORE IMPORTANT METALS.

Name of Metal.	Symbol.	Atomic Weight.	Specific Gravity.	Specific Heat.	Melting-Point (° C.).
Aluminium ..	Al	27·00	2·60	0·212	625
Antimony ..	Sb	120·00	6·71	0·051	445
Bismuth ..	Bi	207·50	9·80	0·031	268
Cadmium ..	Cd	111·70	8·60	0·057	320
Copper	Cu	63·20	8·82	0·094	1,050
Gold	Au	196·60	19·30	0·032	1,064
Iridium ..	Ir	192·50	22·42	0·033	2,500
Iron	Fe	55·90	7·86	0·110	1,600
Lead	Pb	206·40	11·40	0·031	327
Manganese ..	Mn	54·80	8·00	0·120	1,900
Mercury ..	Hg	199·80	13·59	0·032	− 39
Nickel	Ni	58·70	8·90	0·110	1,420
Palladium ..	Pd	106·30	11·50	0·059	1,500
Platinum ..	Pt	194·30	21·50	0·033	1,775
Silver	Ag	107·93	10·53	0·056	950
Tin	Sn	118·80	7·30	0·056	232
Tungsten ..	W	184·00	19·10	0·033	above 2,000
Zinc	Zn	65·30	7·15	0·094	418

NOTE.—The figures given above are those on which many authorities agree, and are only to be taken as approximately correct, as no two pieces of metal would yield the same result.

TABLE OF CONDUCTING POWERS OF METALS FOR HEAT AND ELECTRICITY.

Metal.	Thermal Conductivity (Ag = 100).	Electrical Conductivity (Hg at 0° = 1).
Aluminium ..	31·33	31·726
Antimony ..	4·03	2·053
Bismuth ..	1·8	0·800
Cadmium ..	20·06	13·95
Copper	73·6	55·86
Gold	53·2	43·84
Iron	11·9	8·340
Lead	8·5	4·818
Mercury	1·3	1·000
Nickel	—	7·374
Palladium ..	—	6·910
Platinum ..	8·4	8·257
Silver	100·0	57·226
Tin	15·2	8·237
Zinc	28·1	16·92

TABLE OF CORRESPONDING TEMPERATURES ON THE SCALES OF CENTIGRADE AND FAHRENHEIT THERMOMETERS.

Degrees Cent.	Degrees Fahr.	Degrees Cent.	Degrees Fahr.	Degrees Cent.	Degrees Fahr.
100	212·0	66	150·8	32	89·6
99	210·2	65	149·0	31	87·8
98	208·4	64	147·2	30	86·0
97	206·6	63	145·4	29	84·2
96	204·8	62	143·6	28	82·4
95	203·0	61	141·8	27	80·6
94	201·2	60	140·0	26	78·8
93	199·4	59	138·2	25	77·0
92	197·6	58	136·4	24	75·2
91	195·8	57	134·6	23	73·4
90	194·0	56	132·8	22	71·6
89	192·2	55	131·0	21	69·8
88	190·4	54	129·2	20	68·0
87	188·6	53	127·4	19	66·2
86	186·8	52	125·6	18	64·4
85	185·0	51	123·8	17	64·6
84	183·2	50	122·0	16	60·8
83	181·4	49	120·2	15	59·0
82	179·6	48	118·4	14	57·2
81	177·8	47	116·6	13	55·4
80	176·0	46	114·8	12	53·6
79	174·2	45	113·0	11	51·8
78	172·4	44	111·2	10	50·0
77	170·6	43	109·4	9	48·2
76	168·8	42	107·6	8	46·4
75	167·0	41	105·8	7	44·6
74	165·2	40	104·0	6	42·8
73	163·4	39	102·2	5	41·0
72	161·6	38	100·4	4	39·2
71	159·8	37	98·6	3	37·4
70	158·0	36	96·8	2	35·6
69	156·2	35	95·0	1	33·8
68	154·4	34	93·2	0	32·0
67	152·6	33	91·4		

CONVERSION OF CENTIGRADE AND FAHRENHEIT DEGREES.

These scales are convertible by the following rules :

$$1^\circ \text{ C.} = \frac{9}{5} \times 1^\circ \text{ F.}$$

$$1^\circ \text{ F.} = \frac{5}{9} \times 1^\circ \text{ C.}$$

Therefore, to convert Centigrade into Fahrenheit, multiply by 9, divide by 5, and add 32.

To convert Fahrenheit into Centigrade, subtract 32, multiply by 5, and divide by 9.

$$n^\circ \text{ C.} = \left(\frac{9}{5}\, n^\circ - 32^\circ\right) \text{ F.}$$

$$n^\circ \text{ F.} = \frac{5}{9}\,(n^\circ - 32^\circ) \text{ C.}$$

WEIGHTS AND MEASURES.

TROY WEIGHT.

4 grains	1 carat (c.).
6 carats, or 24 grains	1 pennyweight (dwt.).
20 pennyweights	1 ounce (oz.).
12 ounces	1 pound (lb.).
25 pounds	1 quarter (qt.).
100 pounds	1 hundredweight (cwt.).
20 hundredweights	1 ton of gold or silver.

IMPERIAL OR AVOIRDUPOIS WEIGHT.

16 drachms	1 ounce (oz.).
16 ounces	1 pound (lb.).
14 pounds	1 stone (st.).
28 pounds	1 quarter (qt.).
4 quarters, or 112 pounds.	1 hundredweight (cwt.).
20 hundredweights	1 ton.

METRIC EQUIVALENTS IN ENGLISH MEASURES.

1 millimetre	= 0·03937 inch.
1 centimetre	= 0·39371 inch.
1 decimetre	= 3·93718 inches.
1 metre	= 39·37 inches, or 1·093 yards.
1 inch	= 2·539 centimetres.
1 foot	= 3·0479 decimetres.
1 cubic centimetre	= 0·061 cubic inch, or 0·00176 pint.
1 litre, or 1,000 c.c.	= 61·027 cubic inches, or 1·76 pints.
1 cubic inch	= 16·38 cubic centimetres.
1 gallon	= 4·543 litres.
1 milligramme	= 0·0154 grain.
1 centigramme	= 0·1543 grain.
1 decigramme	= 1·5432 grains.
1 gramme	= 15·4323 grains.
1 kilogramme	= 15,432·34 grains.
1 grain	= 0·0647 gramme.
1 gramme	= 1 cubic centimetre.
1 cubic centimetre	= 17 minims.
1 ounce troy (480 grains)	= 31·1034 grammes.
1 ounce avoirdupois (437·5 grains)	= 28·30625 grammes.
1 kilogramme	= 2·2046 pounds.
1 pound	= 0·453 kilogramme.
1 litre	= 0·220 gallon.

TROY WEIGHT.

(*Used only for Gold, Silver, and Platinum.*)

24 grains .. .. make 1 pennyweight (dwt.).
20 pennyweights ,, 1 ounce (oz. tr.).

Apothecaries, in compounding medicines, subdivided a troy ounce into 8 drachms, a drachm into 3 scruples, and a scruple into 20 grains.

The pound troy, containing 12 ounces, is not used now.

AVOIRDUPOIS WEIGHT.

16 drachms .. .. make 1 ounce (oz.).
16 ounces .. .. ,, 1 pound (lb.).
28 pounds .. .. ,, 1 quarter (qr.).
4 quarters, or 112 pounds ,, 1 hundredweight (cwt.).

20 hundredweights .. ,, 1 ton.
437½ grains .. .. ,, 1 ounce avoirdupois.
480 grains .. .. ,, 1 ounce troy.
7,000 grains .. .. ,, 1 pound avoirdupois.

METRIC MEASURES.

(*The most important measures are in heavier type.*)

MEASURES OF LENGTH.

10 **millimetres** (mm.) .. = 1 **centimetre** (cm.).
10 **centimetres** .. .. = 1 decimetre (dm.).
10 decimetres .. .. = 1 **METRE** (m.).
10 **metres** .. .. = 1 decametre (Dm.).
10 decametres .. .. = 1 hectometre (Hm.).
10 hectometres .. .. = 1 **kilometre** (Km.).

MEASURES OF AREA.

100 sq. **millimetres** (sq. mm.) = 1 sq. **centimetre** (sq. cm.).
100 sq. **centimetres** .. .. = 1 sq. **decimetre** (sq. dm.).
100 sq. **decimetres** .. .. = 1 sq. **metre** (sq. m.) = 1 **centiare**.
100 sq. metres .. .. = 1 sq. **decametre** (sq. Dm.) = 1 **are**.
100 sq. decametres .. .. = 1 sq. hectometre (sq. Hm.) = 1 **hectare**.
100 sq. hectometres .. = 1 sq. kilometre (sq. Km.).

MEASURES OF VOLUME.

1,000 **cubic millimetres** (c.mm.) = 1 **cubic centimetre** (c.cm.).
1,000 **cubic centimetres** .. .. = 1 **cubic decimetre** (c.dm.).
1,000 **cubic decimetres** .. .. = 1 **cubic metre** (c.m.). = 1 **stere**.

Measures of Capacity.

10 **centilitres** (cl.) .. = 1 **decilitre** (dl.).
10 **decilitres** .. .. = 1 **LITRE** (l.).
10 **litres** .. .. .. = 1 **decalitre** (Dl.).
10 **decalitres** .. .. = 1 **hectolitre** (Hl.).

NOMENCLATURE OF ELECTRICAL UNITS.*

A unit of resistance is termed an "ohm," and is equal to that offered by 1·0486 metres length of mercury of 1 square millimetre section at 0° C.

A unit of electro-motive force (E.M.F.) is called a "volt."

A unit of strength of current is termed an "ampère," and is the strength produced by an E.M.F. of 1 volt in a circuit having the resistance of an ohm.

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* Gore's "Electro-Metallurgy," p. 387.

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